THE BOOK WAS DRENCHED

METHODS *in* BIOLOGY

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Author: New Introduction to Biology
Workbook in Biology

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—To Interest the Student in the World in Which He Lives

—To Equip Him With the Scientific Method for Interpreting That World

PREFACE

THE EXTRAORDINARY DEVELOPMENT OF THE BIOLOGICAL SCIences since the beginning of the century has made it increasingly difficult to select material for use in elementary courses in the high school and college. But nowhere in the literature does there seem to be an adequate realization of the fact that the choice and organization of teaching materials now involve problems which are fundamentally different from those presented a few decades ago when biology was only a circumspect portion of the whole which it is today. It is one of the functions of the present volume to show how the materials of the modern science may further the ends of modern pedagogy.

Ten years ago a program of reorganization such as we now present would have been little more than untried theory. In the decade, however, thousands of teachers have experimented with diverse techniques, and several million students have come under the influence of the modified courses in botany, zoology, and more general biology. On a bit of this accumulated experience the present volume is based.

Also during the past decade, the pedagogical investigations of science teaching have been built into a long list of titles. It will be of interest to know which of them are soundly enough established to contribute to the art of science teaching. The present volume attempts to coordinate these more objective studies with the accumulated wisdom of the many who have contributed to the present quality of teaching in the biological sciences.

Throughout the discussions of materials and techniques, we have maintained that there must be a wider recognition of the interests of the boys and girls, men and women—average future citizens—who make up the body of students in our elementary

classes, both in the high school and in the college. It is not a laboratory science, but an out-door biology that they need—a science that can be translated in terms of the living world through which they move.

This volume must presume some previous contact with general educational theory. The immediate consideration of such things as objectives, motivation, unit organization, textbook analyses, tests and measurements, teacher training, etc., must be limited to those aspects of the questions which enter into teaching in the biological sciences.

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CONTENTS

PART I. VIEWPOINT AND CONTENT

PART II. SPECIAL TEACHING PROBLEMS

PART I

VIEWPOINT AND CONTENT

CHAPTER I

OBJECTIVES[1]

AMONG THE SUBJECTS OF THE high school and college curriculum, there is probably none that has had more varied treatment and evaluation than the introductory course in general biology. Biology has been credited with "serving a greater number of the ends of education than any other single subject" in the schools. Within a twelvemonth of this judgment, biology had been criticized as "a survival of an early stage in the pedagogy of the subject which has no place in a modern educational scheme."

This diversity in evaluations is matched by, and probably finds some explanation in, the diversity of the materials included in the subject as it is taught today. A survey of high school and college courses indicates that some of the students are studying the morphologic details of limited series of plant and animal types, while others are being introduced to diverse aspects of a large number of the plants and animals with which they come in contact; that in some classes textbook facts are taught as so much Latin grammar and sentences to be memorized and dissected, while in others the teachers are trying to illustrate scientific method by using demonstrations, laboratory, independent projects, and fieldwork; that we are, in short, not quite clear whether Mendelian heredity or the physiologic effects of cigarettes and coffee; whether crayfish endopodites, exopodites, and basipodites,

[1] Part of the subject matter of this chapter was included in an article by the author in the *Journal of the Michigan Schoolmasters' Club* for 1929, and reprinted in *School Science and Mathematics* 30:374-384.

or artificial resuscitation; whether the concept of evolution, or the daily use of the toothbrush, are the more important materials to present the average future citizens who sit in our classrooms.

An examination of current textbooks and state syllabi similarly shows: (1) that biologic science is presented as a half-year of botany followed by a half-year of zoology, or as a unified course concerned with generalizations applicable to all organisms; (2) that some teachers prefer the type course, with its detailed studies of a limited number of species supposedly illustrative of the major phyla and classes, while others emphasize principles for which a host of common plants and animals may be used in illustration; (3) that some courses are almost exclusively morphology and physiology, while others include a summary of five or six more of the biologic sciences; (4) that it is debatable whether a so-called pure science or an applied science, particularly in its bearing on human hygiene and sanitation, is more profitable for an elementary student.

It seems not unlikely that a wider consideration of the functions of this introductory course might effect some resolution of these conflicting opinions as to its content. While there can be no wisdom in precisely standardizing any program in our teaching, we may find common aims to which to adapt the varying materials that best satisfy our individual needs.

We are, above all else, concerned with the relation of this introductory course to high school boys and girls, college men and women, who will go into nearly every walk and profession in life except that of teaching or of research in biology. They are the ones who constitute the bulk of the students in the secondary schools; they are the ones to whose liberal education the colleges should be contributing. There can be no justification for distorting a program for the one student, among many hundreds or thousands, who may engage in biology as a profession. The introductory course must serve average future citizens.

Inquiring among high school and college teachers, one may find many reasons given for the inclusion of the biologic sciences in the curriculum. Many of these reasons are specific items, some of them fundamental principles, most of them quite worthwhile objectives. But among all of these, there are two which

seem to be more inclusive and of vaster importance than any of the others which are commonly listed. We want, first of all, *to interest the student in the world in which he lives;* and, secondly, *to equip him with the scientific method for interpreting that world.*

INTERESTING STUDENTS

My concern with the first objective originates in the fact that I was born in the heart of what was reputed to be the most densely populated square mile in the country. In lieu of woods and fields, there were the stones of the streets and the buildings, people, cats, dogs, horses, sparrows, the weeds of the vacant lots, and the frustrated plants of the mostly barren back yards. There was the cramped vision that is the lot of the boy in the city. I have some sympathy for the city schools which attempt to make biology practical for that boy by presenting him with the materials of hygiene, and of civic biology. But it seems still more important to convince him that it is an endlessly interesting world in which he is living.

When, some years later, I was taken to a suburban town to live, a new world suddenly opened before me. There were birds with colored breasts, flowers that could be picked, endless things to discover, an inexhaustible treasure chest that drew me on into the fields and over the hills—onto the out-of-door paths which I still follow.

Since the day when I picked my first heal-all and first saw the spot on the song-sparrow's breast, I have led many other boys—and girls—into out-of-door paths, and found them as thrilled as I was to discover them. I have taken boys from the city slums and seen their eyes moisten at the sight of a robin, and at daisies that could be had for the picking. I have taken them from homes of luxury into the glories of swamps and mountain trails. I have shown the farmer's lad something of his fields and woodlands, and displayed the marvel of seed and of egg even to the surprised eyes of the farmer. I have taken city-bred boys to the tops of their first mountains, with their winter-wrens and snow buntings, dwarf trees and Arctic flowers, sweep-

ing winds and breath-taking treasures. With the southern planter I have thrilled at the flame of the sweet gum. With the cowman I have marvelled at the thorns of the desert. I have shared something of the quiet interest of the backwoods native who goes forth for "yarbs" and for "posies."

And for all of them, there seems to be one greatest need: To know that it is an interesting world in which they are living.

If biology has in it that which may be of dollars and cents value, it is still more practical when it interests boys and girls, men and women, in the world in which they are moving. If it is of vast importance that they know how to live, it is more important that they become convinced that it is worth living.

There are few who find life the intensely interesting thing that it may be. There are many who find it a harsh struggle for the bare necessities of existence, for bread, and for shelter.

There are "successful" men, as the world rates them; men at the heart of big business, storing up means for enjoying the years that lie ahead of them. But when they ultimately draw the financial rewards which the world can give them, the homes, the leisure, and the other comforts that can be purchased, will they find it a worth-while world into which they are retiring? Will they have an entrance to the literature of the ages? Will the marvels of gramophone and radio bring them jazz, or the superb renditions of the great masters who are, today, at the command of those who have learned to listen? Will modern motors, on modern highways, invite them to skim through this glorious world, or will they have learned to take time to see it?

By travelling hard it is possible for one to leave the North Rim of the Grand Canyon in the morning, stop in Zion at noon, and be at Bryce's by sundown. Golf-hosed and plus-foured, he has made the journey. Now he puffs up the trail to the lookout where we are standing. We have been away from our native heath long enough to recognize his metropolitan accent and the smugness of his thinking. True salesman, he exhibits the canyon. "This," he says, "is what they call Bryce's. Come, Lucy. From here you may see it, all of it, at a glance. But—" with a sigh, "it's like what you saw at the North Rim this morning." And

he and Lucy, having seen it all, are already trudging back to the hotel, there to wait until they can be on the road again, on the morrow.

At the North Rim, in the midst of the most marvellous forest and the most interesting island fauna in the whole of the Rocky Mountain area, overlooking the most inspiring bit of geology that one may ever see, there are more of these tourists: indoors, dancing to radioed jazz, in the ball-room that a thoughtful government provides for those who find the canyon uninteresting!

The cowman, living in that same stretch of southwestern desert, is similarly warped in his thinking. But the world, for him, is to be measured by the number of cows that will grow in it. He eyes us, suspiciously, as we poke around the oak scrub. He watches us gathering insects, and suspects that we are connected with the forest service. "Why," he sputters, "do you try to make trees grow here? Y' can't feed one cow on an acre of them!"

Whether it is for the boy of the city or the lad on the ranch in the desert, we need a biology that will interest him in the world in which he is living!

In an age of intense specialization, it becomes vital that each of us has some breadth of culture on which to orient our more special interests. In the training of the merchant, the lawyer, the banker, there should be included some fine arts, some literature, some music, and an introduction to everyday plants and animals. They will be better merchants, lawyers, and bankers if they understand the greatness of the world's best literature, or are moved by the chords of a symphony. They will be better men for knowing something of the life which is about them.

In a day when widespread collapse has made us re-valuate our social and economic structures, we, as teachers of biology, have an increasing responsibility to educate men and women for the leisure that modern civilization may bring, as well as for the business and trades by which that leisure will be created. In the cultural, non-professional, non-economic, but soul-feeding aspects of the biologic sciences we may find the chief justification for their inclusion in the curriculum.

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* Recommended as the best reference for student use.

CHAPTER II

DEVICES FOR INTERESTING STUDENTS

TEACHING, IN THE LAST ANALYSIS, CAN be little more than arousing the student, by fair means or foul, to the point where he will by his own efforts acquire the knowledge which we wish him to share.

Without an interest in the subject matter, the student may be driven to memorizing enough of the specific facts to pass the final examination—promptly to forget them as soon as the grades are registered. With his interest aroused, the student will see to it that he masters and retains all the specific knowledge about the particular plants and animals, the human hygiene, or the civic science that will serve his particular ends.

Too often the year's accomplishments are measured by the number of facts which the class has acquired. Though our objectives may be defined as *interesting the student in the world about him,* and *developing within him some respect for the scientific method,* the older types of examinations and, to an even greater extent, new-type tests rank him on the basis of facts memorized. State standardizing agencies, College Entrance Boards, and the admission requirements of State Universities—all of them with far-reaching influence in determining what is actually taught in the secondary schools—give credit for little more than facts memorized. Under such circumstances the sciences find as much but no more justification in the curriculum than Latin or Greek grammar, or the memorization of the names

of the Pharaohs of Egypt. In the effort to pass on facts, we often kill the beginner's interest and close our approaches to him. Theodore Roosevelt testified that the biology teachers were the ones who discouraged him from becoming a naturalist.

It is objected that time spent in arousing interest reduces the time available for teaching facts. Facts are seen as tangible items by which to measure the efficacy of one's teaching. This is in accord with the prevailing American practice of considering dollars and cents as more real than other values. Moreover, there still survives a mid-Victorian attitude which considers the interesting aspects of any subject unsound, perhaps immoral, at best "gingerbread" which is not good for youth in training. While neither sound bodies nor sound minds can be built upon sweetmeats alone, sugars do have food value; and if enough appetizers and tidbits are included to keep the meal from becoming monotonous, even beginning students can be led to appreciate a balanced diet.

If we should name the men and the women who have contributed most toward the shaping of our selves, would they not prove to be teachers who awakened in us a desire for self-education? History is not much concerned with what Mark Hopkins taught at the other end of the log, but it will never forget that he was an inspiration to those who sat with him.

In our particular science, we have the opportunity to introduce the living world to the youth who lives in it. We want him to know the glories and the beauties and the crowding wonders of every highway and by-path of life. If his interest can be aroused in the inexhaustible story of living things about him he will find no corner of the world lonely, nor the everyday items of the world monotonous.

DEVICES TO INTEREST

With these as our aims, it is legitimate to look for ways and means of interesting our students.

Use live material. To everyone who has any memory of his own youth, it would seem obvious that the biology course

should center about live material and living processes. It does not take questionnaire research to discover that animals usually offer more attractions than plants, primarily because animals move and exhibit the activities of life more than do plants. Young children, learning to talk, acquire the names of animals sooner than the names of trees or flowers. For most of us, moving objects, animate or inanimate, distract us from almost any other occupation.

But State Teachers' Associations still, on occasion, discuss the vitalization of the biology course. To ask how to put *vita* (Latin, *life*) into the study of *bios* (Greek, *life*), is to admit that biology is not always the science of life! It is, in truth, often no more than a succession of pickled worms and dead cats, of microscopic preparations and dried fungi, a parade of technical names for nerves and muscles of unfamiliar creatures, a full semester of morphology, form, and structure which too often fails to arrive at the consideration of function. University courses are often much worse in this regard than the average course in the secondary schools.

Biology will interest students whenever it becomes biologic. This means:

Emphasizing functions instead of structure.

Emphasizing how plants and animals live, what they do, and how they grow; not building the course about their structure.

Making it evident that structure is studied primarily for the sake of explaining function.

Emphasizing physiology, ecology, and behavior, which, rolled into one, are the essence of the old-fashioned natural history.

Keeping live plants and animals in the classroom.

Using considerable live material (live chick embryos, live earthworms, live and whole plants) in the laboratory.

Making fieldwork a prominent part of the course.

Utilize familiar organisms. There are horses, dogs, men, and cats, common grass and commoner weeds, houseflies and June bugs, dandelions, and plantains with which every student

is already familiar. Finger nails and sweat glands may serve for adaptations, instead of Darwin's classic examples from India or Madagascar. In the Middle West, it is reasonable to emphasize the phyla which are found in the Middle West, instead of giving most of the semester to forms that are shipped from the marine biologic supply house. It is reasonable to reconsider the choice of the biology text if it is built about the apple tree and codling moth, when we live in a region (and there are many such) where apples are as rare as orange trees and redwoods are in New England. It is best to utilize that portion of the world which may be seen with the naked eye, instead of the microscopic protozoa and algæ about which advanced courses are built. Vascular bundles may be found in a celery stalk or plantain stem, rather than in the prepared sections from the supply house. The microscope has little place in a course for beginners—it is probably best to drop it entirely from the secondary school, unless a single instrument is reserved for a few demonstrations. It is better to study pond scum instead of *Spirogyra*. It is better to give most of the semester to everyday objects of the more familiar phyla (seed plants, arthropods, and vertebrates), instead of filling it with microscopic bits of organisms which have theoretic significance only for the research student.

We follow an old and sound principle when we proceed from the familiar to the unknown. For the elementary biology course, we might even stay largely with the familiar. It will take most of a year to put into order the biologic knowledge which the average beginner already has when he enters the class. The organization of this knowledge cannot fail to interest the young student.

Avoid technical terms. Avoid that pretentious array of polysyllabic derivatives of Greek and Latin roots which, for too many people, is the hallmark of science. With this high-sounding vocabulary biology has been more cursed than any of the other sciences. Much of it is necessary for precision in technical publication. The ancient language bases of such terms contribute toward an international vocabulary which research workers find

valuable. But these are no reasons for flaunting such vocabularies before beginners.

Avoid technical terms as though they were the germs of plague. Many teachers seem to cultivate them. In a recent text written for high school beginners there are 339 distinctly technical terms, a good hundred of which seem unnecessary; and in another book with a glossary of 573 terms there are 363 for which much simpler, everyday words could be found. Powers (1926) considered that over 80 per cent of the technical terms in science texts and books were so uncommon as to present special difficulties to students. In the first lesson in one introductory course in college zoology there appear such terms as *protoplasm, cytoplasm, epithelial cells, Elodea, cellulose, peripheral layer, vacuoles, nucleus, choloroplast, cyclosis, colloidal state, polyphase, emulsoid, suspensoid, dispersed phase, discontinuous phase, continuous phase, Brownian movement,* and *phase reversal in emulsoids.* All in a course designed for everyday students whose native tongue is English!

Very often these technical terms have English equivalents which are quite as precise. *Egg-laying* is an exact translation of *oviposition; anterior* is no better than *front; phototropism* is, precisely, *a reaction to light; Platyhelminthes* means *flatworms; pubescent* means *downy;* and *linear* is, after all, only *line-like* or *narrow.* The *cephalic aspect of the dextral mesoleg of a hexapod* is not a whit different from the *front edge of the right middle leg of an insect.* And *bœufs* are *cows,* and *frondes* are *leaves,* even though some people prefer to apply the foreign term when the one is served on the table, and when the other is found in a fern.

Terms built of familiar words may have the advantage of needing no definition. The gain in teaching value is consequently great. Compare *runner* with *stolen, spore case* with *sporangium, seed plant* with *spermatophyte.* Indeed, the common English term may convey information which no student of the classics would derive from the technical term, as witness *flower-stalk* and *leaf-stem* for *pedicle* and *petiole, gall wasps* for

Cynipidæ, seed coat for *testa,* and the *skin between the legs* for the *patagium* of a flying squirrel.

Some teachers like to use the Latinized forms of the binomial names for plants and animals. They are as much in place in an elementary classroom as khaki at a formal reception, or an evening jacket on a field trip. It was one of the world's leading students of systematic botany who taught us that there are times when it is possible and even desirable to talk about *dandelions* and *oak trees,* even if one does know *Taraxacum* and *Quercus* and many others of that breed.

It is even a question how many of the technical names of the major groups of plants and animals should be given to beginning students. In the secondary school it is possible to use such names as *polyps, roundworms, segmented worms, fish, birds, mammals, mosses, ferns,* and *seed plants;* and no complications seem to develop when these same terms are used with introductory classes in the Universities.

The works of Henri Fabre are an instance of scientific accuracy attained without the use of big words. The greatness of "the incomparable observer" was in no manner hurt by the fact that he avoided technical terms and "used the human language" in addressing young students.

Keep the student viewpoint. We may count it a most valuable asset if we can vividly recall our own reactions to the classroom methods when we were students. For the teacher who can do that, training in formal pedagogy is largely unnecessary. For the teacher who cannot do that, the entrance to good teaching is closed.

The technical vocabularies of so many textbooks, the monotony of the style, and the complexities of the material that is offered beginners are evidences that many writers have not maintained the young student's viewpoint.

We teachers often delude ourselves into believing that we know how students think. But in the three months which may elapse between graduation from college and the assumption of the first teaching duties, a tremendous gulf may develop between our old selves and the new. We become "school marms"

with an oppressing sense of constant responsibilities, a terror of making moves that will mislead our young charges—the traditional primness and fear of futility which stamps the pedagogue wherever you meet him. He talks of sitting hens (though few of them refer to sitting suns), and he doubts the propriety of the use of contractions in a textbook. He is afraid to wear old clothes or khaki on a field trip, to meet the student in fair argument, to show a bubbling enthusiasm over rare flowers or bugs, to engage in circus stunts for the sake of arousing interest in his classes. Afraid to admit how he felt about it when he was young, he loses his ability to know how his students feel about it.

Explore with the students. We may count it an unsuccessful laboratory or field excursion in which we exhibit nothing but the things which we have known before. We must always find something so new that it will awaken our own enthusiasm. On our enthusiasm that of the students may depend. The song of the veery thrush may hold this group of twenty boys for a full half hour, if the song can to that extent capture our own imaginations. They will spend an hour with us, watching the flight of a buzzard, or of a hawk—though they may be bored at ten minutes of classroom biology that has been predigested by the textbook or the teacher.

It is one of the tragedies that we, the teachers, may come to know too much about our subjects. From a musty barrel, we draw out the perfect lecture or quiz, the crayfish demonstration, or stained sections which we have used so many times before that we can explain them without looking at them. Is it any wonder that the class is not inspired? If we have reached the point where we are no longer genuinely enthusiastic about biology, it is time that we looked elsewhere for an occupation.

Use varied methods. The teacher who would avoid the dry rot of teaching must expose himself, as well as his students, to a variety of methods. Like the curves in the woodland road, variety will keep the class interested in what lies ahead, as well as keeping the teacher alive and interesting.

Specifically, a variety of the following techniques and materials may be employed in biology teaching:

- Discussion
- Recitation
- Quiz
- Teacher demonstrations
- Student laboratory
- Fieldwork
- All-day picnics
- Individual projects
- Bulletin board exhibits
- Class projects
- Student reports on special readings or projects
- Lecturettes by the students
- Problem questions for home study
- Demonstrations through microscopes or micro-projectors
- Lantern slide lectures
- Moving pictures
- Outside lecturers (often available through nearby colleges or universities)
- Wall charts, maps, and models
- Bird feeding stations
- Museum collections
- Student care of live plant and animal material (pets, aquaria, terraria, seedlings, flowering plants, rare finds, etc.)
- Borrowed collections (available from some of the larger museums and universities)
- Special readings
- Public exhibits
- Competitions (see the section immediately below)
- Prizes for superior work
- Biology Club
- Junior Academy of Science (with state affiliations)
- Question and answer box

There are obvious dangers in using too many of these devices with any one class. Few of the devices are successful if repeated too often; but as a means of awakening student interest the entire list may be introduced eventually to a succession of classes.

Utilize competitive devices. Competition provides incentives for mature men and women; it is a greater driving force for younger students. Part of the class work may be directed into individual projects, calling for the best that each student can put forth in an independent observation or experiment (see Chapter XIV). In recitations, in group projects, in assigning laboratory material, in making field observations, the class may be divided into two or more groups which are pitted against each other in competition. It is well to acquire a repertory of

competitive games for laboratory and field use. Such devices, while most useful with secondary school students, prove successful even with college and graduate students.

Use narration. We may tell stories about these plants and animals, this living world with which we deal. We may use narration in classroom recitations, in lectures, in the field. It is an ancient, an honorable item of pedagogy, at least six thousand years older than the first methods book, and still an invaluable asset to a teacher.

"Once upon a time," has magic in it that no good leader will neglect to use. Two-year-old Jane has no respect for our order and threats, but she will pause a moment in her tantrum to hear about the "good little girl" whose daddy told her thus and so. John Jones finds other things more interesting than the lesson at hand; but he, the most uncontrollable in the class, will listen to every word of the story of the frozen snakes, of the mating of the salmon or toad, or of the tragedy of the burned forest.

We may well give attention to the art of building stories. There is the significance of the opening stroke. There are the various means of proceeding with the development; of securing suspense; the swift strokes in the climax; the unexpected turn in the ending. The merest item out of our own experience is worth more in our telling than the grandest tale repeated from the great naturalists. We may well forget self-conscious theories and learn to use the first person in our story telling. In such personal touches we may find a fundamental device for interesting students.

If we believe that the art of the teacher depends, primarily, on arousing the interests of the students, then we may find a dozen means beyond the short list here given for accomplishing that end. Using these devices with restraint, never too frequently, varying the methods to avoid monotony, we may proceed in the confidence that when students are interested they will acquire enough of the specific details to ground them in the full science of biology.

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CHAPTER III

TEACHING THE SCIENTIFIC METHOD

ALL OF THE SCIENCES INCLUDED IN the school and college curricula find it among their prime objectives to teach something of the scientific method. It is, however, easier to hand on facts than it is to train in a method, and there are many who question whether we are actually accomplishing very much in inculcating scientific attitudes among students.

There can be no doubt that public acceptance of science in the schools finds its origin in the belief that our present civilization has been peculiarly furthered by the sciences, that this is an age of science, and that one may attain worldly success through the mastery of some science. That this is an age of respect for science is evidenced by the advertising value of the word; that this is an age of science would be more difficult to show. There are few subjects in the curriculum which do not wish to be rated as sciences. Economics and sociology are now social sciences; psychology denies its philosophic origin; home economics is no longer a practical art; history (whose own method of evaluating authority is in reality superior to the scientific use of recorded data) insists it is becoming "more scientific"; pedagogy has become the science of education; and philosophy considers herself the science of sciences. This is the same sort of attitude which makes it necessary that writing paper be made with scientific accuracy, that halitosis be reckoned among the discoveries of science, that underwear and yeast be

endorsed by "a great scientist"—or movie star—and that there be a scientific justification even of systems of theology. It is unfortunate that the real power of science is something less than the magic of its name.

WHAT IS SCIENCE?

Science is defined in a score of ways by students and teachers of science. To some it is a system of precise reasoning; but reasoning reaches its prime development in philosophy. To others it is accuracy in any form; but history, music, and many another field is also concerned with accuracy. Academically, science is induction, one of the methods for logical reasoning; and while this is basically correct, it is safe to say that there are few research scientists who consciously follow a particular system of logic. To many, science is synonymous with the experimental method; but there are some fields in science (several in biology, for instance) in which few experiments are performed, and in all fields of science observation unaided by experiment is a constant source of data. To some it is the material of the science which makes it scientific: biology is considered a science because it deals with living things; music an art because it deals with musical phenomena—and it is obviously a simple matter to extend the list by arguing a new lot of materials into the meaning of the term.

To many, science even appears to be a system of technical terms, and the definition of these terms constitutes the training given in too many science classes.

But science seems best defined as a method of obtaining knowledge through observation. It may ultimately arrive at a body of generalizations based on these observations, and even relate the observed phenomena in a reasoned system of cause and effect; but with the making of observations the scientist most often fills his hours and days. Most scientists admit a lack of confidence in even the simple reasoning by which they derive their conclusions, but they consider adequately controlled observations as among the few verities of the universe.

Because of the nature of its method, science is capable of dealing only with matter. Matter can be observed, other things cannot. Things that can be tasted, touched, heard, and seen, things that can be measured and weighed, things that have substance—these are the materials of science. Exceptions appear in psychology, which is often limited to considering the results of phenomena, and not the phenomena themselves. Further exceptions appear in the physics of energy and atomic structure where, more recently, the science has been utilizing methods which verge very strongly on the philosophic.

That there are realities that are not matter, perhaps most of us would agree. But with them science is not fitted to deal.

It is *art* which must deal with values, measured in the emotional responses which the materials of art may bring. Art is subjective, science is objective. In art each individual may determine the value of any object or event by noting the emotional pleasure or pain they bring *him*. Such evaluations are valid for the individual, though they may differ—as the emotional responses differ—in different individuals. If it is a Sibelius Symphony that most stirs me, I cannot deny that blared jazz may mean more to my neighbor. If it is a mountain landscape that moves me, I cannot deny that wide expanses may bring greater satisfaction to some dweller in the plains. Art is individualistic; but science confidently searches for truths on which qualified observers may agree.

Ethical evaluations, questions of good and bad, of better or worse, of right or wrong, are, like determinations of beauty, matters outside of science. Science counts the vibrations of the strings, art or ethics brands the tone as good, bad, or indifferent. Science may observe the effect of alcohol on nerve muscles or germ cells, but—some opinions notwithstanding—it is not the business of science to evaluate the social significance of intemperance. There are no scientific arguments for any scheme of morality, for any system of action, for any interpretation of a God. If science contributes to good citizenship, it is a happy circumstance, but it is not the inevitable attribute of scientifically determined truth. There is, too often,

a confusion of social problems, questions of pedagogy, artistic values, and science.

Assumptions, hypotheses, and reasoned conclusions are typically tools of the philosopher. When scientists use such tools, as admittedly they do, they enter paths which diverge from those of true science. A scientist must constantly guard against confusing his observations with his reasoned conclusions.

The generalizations in which science deals are not to be confused with reasoned conclusions. They are, rather, summary statements which should accurately include all of the specific observations on which they are based. Well made, they can be as accurate as the individual observations from which they originate. Obviously they cannot cover observations which are unknown to the maker of the generalization. Generalizations must be modified as soon as specific instances are discovered which invalidate or extend the original statement.

In classroom instruction and in texts, what may appear to be statements of fact are often generalizations. Sometimes they are based on only a few observations, and are liable therefore to modification by data from the next observer. It is to be expected that the beginning student will find textbook statements which do not agree with his own observations.

It is a common error of textbook writers and of teachers to extend generalizations beyond the particular species on which observations have been made. For instance, it is often said that mammals (implying all mammals) give birth to living young; it is said that all plants and animals demand oxygen for respiration; other physiologic data, usually based on vertebrate or, more specifically, on human material, are presented as principles applicable to all animals. Such statements are misleading. It is true that pedagogical considerations demand that concise generalizations be given beginning students without naming the exceptions which, in a more complete statement, would weigh them down. But the inaccuracies usual in generalizations may be eliminated by a more liberal use of temporizing adjectives. If, for instance, it is said that "nearly all mammals," or "many animals," or "some organisms" are

thus and so, the beginner has sound generalizations on which he may add the exceptional and new data that he will later discover.

RESPECT FOR OBSERVATION

All men are inclined to believe what they see. A scientist differs from the average man only in having a more profound respect for observation as a means of obtaining knowledge about the material portion of this universe.

That the popular respect differs from the scientific respect for observation is evidenced by the several substitutes which are commonly accepted as means of obtaining knowledge even about matter.

The word of another person, and the printed word are, for many, the final sources of truth as well as of wisdom. Authority, these second-hand sources of information are called. Like prophets from strange countries, authorities have a popular prestige. Their findings seem so much more convincing than one's own observations!

Then there is reasoning, the tool of the philosopher. It is popular, one is inclined to believe, because arm-chair solutions are easier to make than observations based on actual materials and phenomena. Our educational systems have fostered such undue respect for reason that the word "academic" has acquired an unsavory connotation which is quite the opposite of the word "scientific."

There is wishful thinking, sometimes disguised as ideals, or faith. It often represents nothing more than an ostrich interpretation of what the world ought to be, instead of what the world is observed to be.

Where material phenomena are involved, science accepts none of these substitutes. If observations are available, science accepts them as against popular opinion, logical reason, faith, or creed. Where observations are not available, science must admit ignorance and refrain from offering opinions.

This scientific reliance on observation provides a simple and very natural method of obtaining information about matter. It is naïve in its simplicity. It is so natural that one might expect the babe, placed on the desert isle, removed from contacts with other human beings, to develop attitudes more scientific than those of most men.

Johnny Jones (whose history has served us before) was born with a considerable disposition to use the scientific method. He first learned about things by grasping them, by tasting them, by looking at them. He first learned the properties of matter by bumping into it. His early respect for energy was learned by direct contacts with it. His first generalizations were based on his own and not on anyone else's experience.

Johnny Jones would have learned more, in the scientific manner, if his mother had not taught him that there are substitutes for observable data. When he fell down stairs, he was thrashed because he had not taken her word that he would hurt himself. He was introduced at an early age to "they" and "it" as sources of authority. "Respect due his elders" was inextricably associated with an acceptance of their observations, their imaginings, their desires—things that small boys were supposed not to question.

Having lived through a dozen years of suppression of his scientific self, Johnny enters our class as a freshman. Do we encourage his dependence on what he can see, or do we resort to the school library and Johnny's own text as an ultimate source of information? How often do we ask him to collect, order, and correlate his own observations, made during classroom demonstrations, in the laboratory, in the field, and at home; and how often do we ask him to memorize definitions and laws and main points of an outline? How much importance do we attach to the facts that he acquires, and how much to the *way* in which he acquires them? Will Johnny Jones leave high school with the docility and sophistication becoming to prospective college freshmen, or will he still respond to the invitation to explore the world about him?

TEACHING THE SCIENTIFIC METHOD

Any formal consideration of method must be brief with beginning students, and is probably best left to the end of the year when it may be presented as a summary of the methods the class has actually employed throughout its studies.[1]

Effective teaching of the scientific method must depend upon a whole-hearted use of that method by the teacher throughout the course in biology.

Students should be encouraged to make abundant observations, in the laboratory, in the field, and at home. To prove that observation is considered to be the most important part of the work, the teacher must give it plenty of time and base a large proportion of all tests and awards on it.

From the beginning, the student should be convinced that the teacher will actually rate personal observation above textbooks, reference book, or any other data.

The student should be led to develop a critical and sceptical attitude toward textbook and all other second-hand sources of information. When the student's carefully verified observations disagree with the text, accept the observations as the final authority.

In using textbook authority, the student should constantly evaluate the bases of the statements therein, depending most upon those which can be recognized as coming from the author's first-hand observations.

The student should be expected to illustrate all textbook generalizations (biologic principles) with specific instances, preferably with those drawn from his own experience.

The relation of cause and effect may be emphasized by continually asking the students to explain the factors which account for the facts that are observed or acquired from second-hand sources. "Why is this so?" should not come to mean "What is

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[1] For such a characterization of the scientific method, designed for elementary student use, see Kinsey, 1933, *New Introduction to Biology*, pp. 773-781.

the purpose of the thing"; the question should be a demand for an exposition of the *cause* of the phenomenon.

In examinations, do not depend wholly or even primarily on definition questions, true-false, multiple-choice, completion, or other new-type tests, for they are almost always tests of facts memorized. Utilize discussion and problem questions often enough to test the student's ability to organize his observed data, to generalize upon them, and to relate them as cause and effect (see Chapter XVII).

Beginning students, even in the high school, *can* be impressed with the idea that memorization of facts is not the fundamental thing in the scientific method. It requires, however, a teacher who believes there is something more important than memorized facts, to get this idea across.

Do we, at heart, want John Jones to grow into a man who is not dependent on newspaper science, or the biology of a silver-tongued statesman? Do we want him to have some better reason than the school book command for cleaning his teeth, choosing a balanced diet, and making a profitable distribution of work, rest, and play? Do we hope he will become the sort of man who believes neither in the complete depravity of all politicians nor the unimpeachable altruism of his political candidate; whose acceptance of established biology will lead him to having his children vaccinated and who will submit himself to vaccination; who is cautious of the gossip which makes social small-talk, but who treasures the verities of observed data as against all authorities, ancient and modern, and against fashion, creed, convenience, and cult; whose respect for observed truth will extend even to the truth that may be unpleasant, uncomfortable, and not beautiful but true; and who feels no impulsion to reach conclusions on all questions of state and society, religion, education, vitamins, and ethics—a man who will sometimes say "I don't know," or "I wonder"? Somewhere, among the species and organs and calories and genes and facts upon facts which constitute biology, there is the making of that man, if we really believe his type is worth making!

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CHAPTER IV

THE ART AND SCIENCE OF TEACHING

WITH SCIENCE PRIMARILY CONCERNED WITH knowledge obtained through direct observation, and with evaluations restricted to ethics and art, it may fairly be asked whether teaching is an art or a science.

But there is both an art and a science of teaching. One may consider all of the observed data which have any bearing on an issue; but one's use of scientifically derived knowledge will depend on his evaluation of the significance of the data. All of the applied sciences are, in actuality, practical arts. The successful teacher will command both the science and the art of teaching.

THE SCIENCE OF TEACHING

Only recently has there been an attempt to establish the teaching of science on scientific bases.

In 1929, Caldwell listed the following as the achievements of the two preceding decades of the investigations of science teaching:

1. What should be the content of science textbooks.
2. The vocabularies in common use.
3. How to teach students a scientific way of doing things.
4. How to train science teachers.

To this list we should add:

5. The relative values of laboratory, teacher demonstration, and other techniques.
6. Methods for testing student achievement.

Scientists are, naturally, much interested in finding the precise data which have been obtained to date, and hopeful for further achievement in the direction of pedagogical investigations. At the same time it is not surprising that their scientific training leads them to be as critical of educational science as they are of observations and measurements in research in the biologic and physical sciences.

In 1931 Curtis, after a sympathetic review of the most significant work in the field of science teaching, listed these as serious criticisms which pertain to many of the learning studies:

1. Failing to state the problem definitely.
2. Assuming the equivalence of experimental groups without taking adequate steps to insure this equivalence.
3. Securing equivalence of groups upon a basis other than that in terms of which results are measured.
4. Failing to isolate the experimental factor.
5. Delimiting too rigorously the teaching methods under investigation.
6. Assuming the definitions of the teaching methods under investigation to be standard, *i.e.*, commonly accepted.
7. Failing to report the technique in sufficient detail.
8. Mingling findings and conclusions with details of method.
9. Evaluating on the basis of only one criterion, when that criterion is but a single element in a more complex process or situation.
10. Employing crude subjective tests in measuring results.
11. Making gross errors in recording data.
12. Including personal opinions among the findings and introducing personal bias into the investigation.
13. Making sweeping generalizations from obviously insufficient data.

Curtis adds that "the merits of these investigations [of science teaching] greatly outweigh their demerits"; but his criticisms so fully embody the questions raised by research scientists that it will be understandable why we are sceptical of the claims made for some of the pedagogical studies of science teaching.

The content of science texts. The contributions in this field have been questionnaire studies of the actual content of biology courses in typical or superior high schools, questionnaire surveys of the opinions of university and college teachers (many of whom have not had even the remotest contact with the high school program), determinations of popular interests in biology as evidenced in current newspaper and magazine articles touching plants and animals, and classroom student reactions to the diverse materials of the subject. As samples of what is actually being done and of existent opinions these studies are scientific enough, though we may question how adequately they represent the opinions of any large part of the teachers or of the public. What the facts ascertained by such studies should mean in the practical art of teaching is further to be debated, although the dull monotony of certain of the current texts may indicate that some authors attach much significance to these studies. To many science teachers the investigations appear to be an appeal to the *status quo* in justification of the *status quo,* and to offer no means of advance in teaching techniques.

The vocabularies in common use. There have been comparisons of current texts with word lists representative of the vocabularies already possessed by students entering elementary classes. In several fields word lists have been among the most significant of the scientifically discovered tools, and they may well be considered in biology teaching. But it may be said again that a vivid memory of his own early reactions to technical terms, and a sympathetic awareness of student modes of expression are the best guides for keeping a teacher's vocabulary within reasonable bounds.

Teaching the scientific method. Although it is claimed

that there are scientific studies on how to teach the scientific method, the problem seems one of applied art, and there seems no scientifically established material on this question. Downing's interest in this subject, cited by Caldwell (1929), has been productive of good results; but the bases for many of Downing's conclusions seem evaluations made by a good teacher, and not objective studies in science.

What to include in the training of science teachers. Caldwell points out that studies of the careers of Ph.D.'s indicate that 75 per cent go into teaching, and rightly contends that the preparation of advanced students should recognize the use to which they put their training. These simple data obviously indicate that there is much to be done in modifying the subject-matter courses in the colleges and universities.

Relative values of laboratory and other techniques. These studies have attracted considerable attention, and are sometimes accepted as substantial contributions to the science of teaching. A more detailed analysis of them is presented in Chapter XII on *The Significance of the Laboratory.* There the conclusion is reached that the studies have brought about a long over-due re-valuation of techniques in the teaching of the laboratory sciences. But as for their scientific nature, they seem nothing more than measures of the memory achievements of certain limited groups of students under certain inadequately controlled conditions. They provide no measures of the efficacy of the prime item, training in observation, for which the laboratory was primarily designed.

Student achievement. The outstanding success in securing scientifically established data has come in the field of mental measurements. The testing devices based on this research are, when adequately built, convenient means of measuring certain aspects of student achievement, even if they are limited in their scope. That new-type tests will find their place in the best teaching practice, we must agree. That the new-type tests are adequate measures of all that a student should accomplish we, as scientists, cannot agree. (See Chapter XVI on *Measurements and Evaluations in Biology Teaching.*)

THE ART OF SCIENCE TEACHING

The argument for the scientific foundation of pedagogical practice is, first of all, based on the contention that the objectives of teaching can be formulated and measured, and that the efficacy in achieving these ends can also be determined by objective means. In this contention there seems a considerable confusion of the meanings of measurement and evaluation. The possibility of reducing phenomena to mathematic terms does not prove that they are matter or energy, which are, after all, the only things scientifically measurable. Most scientists hesitate to accept learning ability, motivations, incentives, attitudes, interests, appreciation, etc., as items that are, in a scientific sense, measurable. To date, practically all of the tests which have been made are of a single phenomenon—factual knowledge acquired—although there is a much longer list of things with which education must be concerned.

As the result of our biology teaching, we hope to interest our students in the world in which they live, and to teach them something of the scientific method. Downing agrees that these are of more importance than the passing on of specific facts; but his own chief contribution to the science of science teaching —his attempt to show that demonstrations are more efficient than individual laboratory practice—is based on a "range of information" test which is no measure of the degree to which the student is interested, or of the extent to which he has acquired the scientific method in his thinking.

It is a question whether human material can be so standardized against controls that it can ever be measured with a precision approaching that of the material sciences. The best measurements that have been obtained apply only to the set-up of the particular experiment. Until they are checked by abundant repetition of the same experiment, by other experimenters, in other classrooms and with other teachers, it cannot be known how much the individual variation of students, teachers, and classroom conditions may modify the results.

It is true that there are some who consider it inconsistent that teachers of the sciences should derive their practice from anything but scientific data. It has been argued that there is no more excuse for settling pedagogic questions by discussion than there is for determining the facts of genetics by that same method. This argument overlooks a fundamental distinction between the observable aspects of a material phenomenon and the evaluation of techniques for securing particular ends in the use of that phenomenon. There is a science of genetics, but it is not the geneticist who grows the bumper crops on the farms, or the prize-winning fruits and flowers in our markets.

To make another comparison: the teacher is like an artist who should know enough of the science of pigments, of the structure of stone, of vibrating strings, or of the mathematics of harmonic sound to make sure that he uses the best available tools. But it is beyond this knowledge that we find most of the art of the painter, of the sculptor, of the musician, and of the composer. Indeed, although average mortals may find a scientific knowledge of their materials contributing to their use of them, it is debatable how much such impedimenta can contribute to the art of a true artist. Great paintings were made before the chemistry of pigments had become a science, there was great music before there were laboratory analyses of sound, and the greatest of the composers have been those who have risen above the rules of formal harmony. It is the artist, and not the professor of physics, who will continue to stir us with his performances; the composer, and not the professor of mathematics, who will continue to write the great symphonies of the world. Unless our prospective teachers have some innate ability in the art of teaching, it will do little good to give them pedagogical tools obtained by scientific measurement.

If we are concerned first of all with interesting boys and girls in this living world, we must have teachers who are inspired and who, in consequence of their own interests, are able to inspire beginning students. If we want to instill respect for scientific method, we must have teachers who have mastered the difficult art of arousing respect for a method. Teachers

who can do these things must be artists, as well as masters of the scientifically established technique which is available for use.

In the discussion of the problems involved in the teaching of biology, we shall, in this volume, try to take into account all of the tools that well-established investigations may have provided; but to date such contributions are really few, and we must draw more largely on that body of experience which, by the subjective standards which artists employ, seems to represent the good teaching which has been done in the presentation of the elementary sciences.

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CHAPTER V

HISTORY OF BIOLOGIC RESEARCH AND TEACHING

SOME UNDERSTANDING OF THE PRESENT CONTENT of the elementary biology course may be obtained from a consideration of the history of the research on which the science itself is established.

SYSTEMATIC PERIOD

Taxonomy is the oldest of the biologic sciences. While primitive man was interested in much more than naming the plants and animals with which he contended for the possession of the earth, or which he utilized in his economy, the first organized biologic science was systematic botany and systematic zoology. That development even antedated Linnæus (whose chief work was dated 1757-59). The successors to Linnæus made taxonomy the dominant science, and so it remained until the development of the German school of morphologists about 1830. Taxonomy was justly reproached at that time for its failure to do more than catalog and name plants and animals, and for its failure to contribute to the solution of broader and more fundamental problems. In consequence systematic science passed largely into the hands of amateurs, while research men turned to morphology and to some other aspects of biology. It is only recently, after more than a century of virtual ostracism from the ranks of the professionals, that taxonomy finds a basis for its revival in the correlation of field data on the nature and origin of species with the data of modern genetics.

Teaching taxonomy. Organized biologic instruction for elementary students began, like the subject matter of the science itself, with a natural history that was built around systematic botany and zoology. That method of instruction began at least a century ago. Such masters of teaching as Henri Fabre (1823-1915) in France, and Louis Agassiz (1807-1873) in our own country, antedate any widespread introduction of natural science into the elementary curriculum.

The beginnings of classroom instruction in the biologic sciences, in America, are usually connected with the rise of the private Academies (established by Franklin at Philadelphia in 1751, and by others in New England and New York State from 1778 to about 1850), and with the introduction of natural philosophy and natural history into the Boston High Schools as early as 1821. Some of the older universities had offered courses in natural philosophy long before that (Harvard offered such a course as early as 1643); but all instruction in those subjects in the colleges was academic and largely designed for advanced students. The first laboratory teaching designed for beginning students in the colleges is credited to Professor E. C. Pickering in the Massachusetts Institute of Technology in 1869, but it was some time after that before the sciences figured prominently in the higher institutions. It was not until the last half of the nineteenth century that they accepted any of the sciences for entrance requirements. The University of Michigan in 1873 was the first to accept a biologic science for entrance. In general, the secondary schools must be credited with having blazed the way in developing the elementary program.

Although the German morphologists began their work early in the 1800's, at about the same time as the elementary schools began shaping their program, the schools did not teach morphology at the start. They taught systematic botany and zoology and the natural history of the material which they classified. For nearly the whole of the century, the collection of specimens, particularly the making of herbaria, constituted the endless routine through which beginners were put. Keys to trees and complete floras were the textbooks, with the out-

standing exception of the introductory portion of Asa Gray's *Manual of Botany* which, where well used, did introduce the student to some morphology and more general materials. In the hands of the better teachers, systematic botany and zoology became the foundation for a very live sort of natural history; but in too many cases it degenerated into a "petal-pulling calisthenics." By the end of the nineteenth century, taxonomy as teaching material had fallen into as great disrepute as taxonomic research.

THE DOMINANCE OF MORPHOLOGY

The reaction to the futility of the older systematics was ushered in, as we have noted, by the German morphologists. The results of their investigations in embryology, histology, cytology, and comparative anatomy were so brilliant that students were attracted to the German universities from all over the world, and morphology constituted nearly the whole of biologic research for three-quarters of a century. Subsequently physiology was built upon morphology (micro- and gross anatomy), and modern genetics has depended in part upon the morphologic science of cytology. To morphology we owe our modern understanding of the cellular basis of biologic structure and function, the origin and gradual development of the new individual from its one-celled beginnings, a goodly portion of the earlier phylogenetic interpretations of evolution, the localization of the factors of heredity, and a long list of other important principles which will always command respect for the science of plant and animal structures.

Teaching morphology. University instruction for beginning students of the biologic sciences began in this period when the German morphologists dominated research and the training of most of the American students of botany and zoology. With only a few outstanding exceptions, the courses in the colleges were, from the very beginning, headed by morphologists. The surprising ability of older men to control the direction of progress is evidenced by the fact that today, a third of a century after morphology has ceased to be the leading contributor to biologic

research, morphologists are still largely in charge of university instruction. More than that, in the period from 1890 to 1916 they largely controlled the content of the high school course by controlling the training of the teachers. Many current texts still perpetuate this attitude. As a result, there was a long period during which secondary school students spent their time worrying over the cranial nerves of dogfish, dissections of various animal types, and the hidden details of the structures of algæ supposed to portray the origin of sexual reproduction among plants. These things represented what the high school teachers had studied in their morphology-controlled university courses.

In 1890 about 60 per cent of the American secondary schools were teaching a biologic science, but by 1920 only about 30 per cent of them offered such studies. Botany had survived better than zoology which, by the beginning of the last-named decade, was represented in hardly 3 per cent of the schools. There are some who believe that the chief cause of this decline was the inability of the morphologists to understand how little pertinency their program had for the boy and girl who was to be the average future citizen.

PHYSIOLOGY

Built upon morphology, physiology did not gain its prestige as a research science until near the beginning of the present century. But it is, statistically, the leading field of research today. The number of investigators in that field, the number of physiologic papers presented at any meeting of biologic societies, and the number of physiologic studies published each year in the scientific journals surpass the total of the contributors and the contributions from all other fields. Directing its most recent attacks on the chemistry and physics of protoplasm, physiology must remain the leading biologic science for a long time to come.

Teaching physiology. In view of the importance of physiologic research, it is surprising to find how little influence that science has had upon the introductory courses in the universities.

On the other hand, the secondary schools, more intimately in touch with the needs of the average citizen, have given more consideration to physiology as a possible relief from the older form and structure program. From the beginning of the present century, there were repeated attempts to introduce more physiology in beginning classes. Some of the best of the University texts (Abbott 1914, Burlingame et al. 1922) found physiology supplying the unifying principles which allowed them to abandon the distinction between botany and zoology, and build a program which deserved to be called biologic.

The high schools first considered physiology at about the same time (early 1900's) that a concentrated effort was being made to turn the introductory course into economic biology. From a combination of these two movements came the human physiology (largely concerned with human hygiene) which is a primary feature of many of the elementary programs today. It is only recently that the basic principles of a more general physiology have appeared in secondary school texts.

THE MODERN BIOLOGIC SCIENCES

With the re-discovery of the Mendelian laws in the first year of the present century *genetics* emerged as a distinct field of research. Although it has hardly more than thirty years to its credit, its specific accomplishments have been great. Even greater, from the standpoint of educational history, were two other contributions which it made. It built the list of biologic sciences to a point where no one could fairly consider morphology and biology as synonymous terms. Secondly, it was a science that, obviously, could not be classified as botany or zoology. Although all of the older subjects were becoming more broadly biologic, it was in genetics that the botanists and zoologists first formed joint societies, established joint publications, and prepared texts that were usable in either botany or zoology departments in the colleges.

In addition to the development of genetics, the first third of this century has seen the establishment of *ecology,* including

such economic subjects as forestry, entomology, economic ornithology, and others, on sounder scientific bases.

There has also been an extension of interest in problems of plant and animal *behavior.*

Recently there has been a revival of *taxonomy,* with its special contributions to distributional biology.

Professional biologists, instead of being centered in a single field, as they were a third of a century ago, now are divided among seven or more fields, all biologic, but each with its own problems and methods. The languages and interests of these several fields are so different that it is difficult for the research man in one to keep in touch with activities in very many of the other fields. Biology has become a group of related but diverse sciences.

Teaching the modern sciences. This multiplication of the biologic sciences has challenged our methods of training students—both those who will become professional investigators in biology, and those who will go into the other walks of life. It is no longer possible to gain any conception of the extent and methods of biology as a whole by concentrating on the study of a single aspect of the subject. But is it possible to give the average student an understanding of the diverse aspects of modern biology without making the introductory course so superficial that it is unsound? Is it possible to get textbooks that will present all sides of the science without becoming encyclopædic, and without undue emphasis on any one part of the whole?

As the several sciences have developed, it has become increasingly necessary for the research workers to become specialists. How should these future specialists be trained? They need, as never before, some conception of the relations of their special fields to each of the other sciences. Unless they can, in their training, secure some grounding in all of the sciences, they are not likely to see the significances of their problems as they lead from the special fields into the other provinces of biology. Every biologist should be able to recognize the limitations of his own field, and have respect enough for the other fields to be interested in coordinating his work with that of other workers.

For the average beginning student, who is not going into biology as a profession, the modern sciences offer more interest than the older morphology. It is no longer certain that the morphology type course is the best contribution that our science can make to the liberal education of these average citizens. The modern sciences provide the occasion for a new and modern consideration of the teaching problems in the colleges and universities; and, to an even greater degree, to the teaching problems of the secondary school curriculum.

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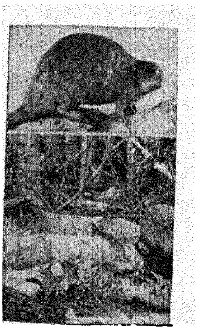
CHAPTER VI

THE UNIFIED AND THE DIVIDED COURSES



IN THE NATURAL HISTORY PERIOD THERE WERE teachers who restricted themselves to plant material or, less often, to animal material; and there were those who included both plant and animal material in their teaching. But with the establishment of university courses in the sciences, the predominant use of morphology made it practically impossible to keep botany and zoology in one department. In morphology the unity of botany and zoology is less evident than in any of the other sciences, and what unifying principles there are were lost sight of in the mass of detail which characterized so much of the instruction of that period.

It is true that the early advocates of the morphology type course, such as Huxley in 1879 and Sedgwick and Wilson in 1895, attempted to include both kingdoms in their introductory teaching; but they effected little more than an alternation of plant and animal morphology in successive weeks of the semester. It was this "fern-earthworm" biology which drew the objections of so many of the now older men, and it is this kind of divided course which is largely responsible for such objections as still remain against the offering of biology.

The development of a more nearly unified program is to be credited directly to the interests of the secondary schools. Faced with a considerable decline in enrollments in high school botany and with even more drastic reductions in zoology, the high school teachers were quick to recognize that a new organization of

material was necessary to re-justify the inclusion of the subject in the public school curriculum. In the first fifteen years of this century an increasing number of voices was raised in support of a full year's program which should include both plant and animal phenomena, with a portion of the year devoted to human physiology. The latter provision reflected the physiology and applied biology movement which had arisen in that same decade. Since the development of the pioneer textbooks in high school biology (Hunter in 1907, Bailey and Coleman in 1908, Bigelow in 1911, Peabody and Hunt in 1912, and Smallwood, Reveley and Bailey in 1916), chiefly as products of the developing course in the New York City schools, the decline in the offering of separate courses in botany and zoology in the high schools of the United States has been steady and considerable. Many of the colleges and the universities, always more conservative, continue to maintain their zoology and botany departments as remote and as antagonistic as they were when their present heads received their training; but among the universities there is an increasing list of institutions (*e.g.* Brown, California, Cornell, Harvard, Indiana, Michigan, Pittsburgh, Princeton, Purdue, Rochester, Stanford, Utah, Yale, etc.) which utilize biology as a part or the whole of their elementary offering.

It has, however, remained a question whether the plant and animal material should be presented in successive periods in the year, or whether plants and animals should be used at every point throughout the course to illustrate principles common to all living things.

FOR THE DIVIDED COURSE

In favor of presenting plant and animal material in successive periods in the year, and even in defense of the complete separation of the botany and zoology programs, the following arguments are commonly presented.

1. **It causes less confusion** in the minds of beginning students if plant and animal materials are segregated.

2. **There is no sound basis for unification** in a study of the *morphology* of plant and animal types. This is apparently true. If the introductory course is built around morphologic types, as it still is in many of the colleges, there seems to be no advantage in combining the two.

3. **It is very difficult to work out a unified course,** even if it were desirable. Twenty-five years ago this argument was a very real one. Today it usually means that the botanist, ignoring the fact that all of his students are animals especially interested in their own animal processes, is objecting to a course in which there is not a strictly 50 per cent representation of plant material.

4. **It is difficult if not impossible to secure teachers** adequately trained to present a unified course. This objection would be more significant if it did not come from the very men in the universities who are responsible for the training of teachers, and who have very often failed to see that the teacher of biology needs a preparation somewhat different from that originally planned for teachers of botany or zoology.

The teacher of a beginning class in botany may be a specialist either in plant anatomy, systematic botany, plant physiology, plant genetics, plant pathology, or plant ecology; but he does not wait until he is a specialist and master in all of those fields before he tries to teach an introductory botany course.

FOR THE UNIFIED COURSE

1. **The living world is a unit.** This is the soundest reason for attempting to present a unified biology course. If we are to introduce students to the world through which they move, we must deal with the intricate realities of that living world. It is easy enough to bring a dead animal into the laboratory and dissect it without thought of the plants from which it secured its food and shelter; but it is impossible to go very far in the study of animal processes out-of-doors, without finding that plants enter into the picture.

I think back to the boyhood day when I roamed the woods and fields in fine ignorance of any distinction that was to be

made between botany and zoology. Between the plant and the bug that fed on it. Between the flower and the bee that came to it. Between the plant tumor and the insect that caused it. Between the green of the clover and the nitrogen factories on its roots and the beef of the cow in the pasture. As my studies have progressed, they have served to emphasize the similarities rather than the differences between plants and animals, and to lead to a study of those inter-relationships which are the realities in nature. In my research, I am studying galls and gall insects—plant growths whose forms are determined by the chemical constitution of the secretions of the insects; insects whose foods and life cycles, choices of hosts, and distribution in space and time are uninterpretable without some knowledge of the plants on which they occur. My problem is in neither zoology nor botany, but in biology. There are many other problems which are as truly biologic. Why should the average boy, or the embryo scientist, for that matter, wandering the paths of this world, be asked to consider insects only as far as they affect other animals, and to wait until another semester or another course before he learns of their relations to plants?

2. **The biologic viewpoint commands student interest.** This is true because some of the most interesting of the life processes (physiology, ecology, behavior) are common to or involve both plants and animals. This is further true because the biology teacher, with the whole living world from which to choose, can draw on an endless store of items to illustrate each principle. Now it is a plant, here it is insect material, there it is a bird that best illustrates adaptations. For learning the principles of classification we may use trees; we may depend on insect data for studying the geographic isolation of related species; we will use both plant and animal material in learning about tropisms. Once having discovered the advantage of using both in his introductory classes, the teacher finds it difficult not to include material from the two kingdoms, even in teaching advanced courses with graduate students. The use of the best of the plant and animal material in a single course seems abundantly justified by the richer nature of the teaching.

3. **Science now knows principles common to plants and animals.** Today the elementary course can be unified as it could not have been a few decades ago. As the result of modern research we have arrived at principles so broad that we find them applicable to both plants and animals. Some of these principles, such as the cellular basis of all organic structures, the gradual development of the individual from the fertilized egg, and the origin of new species by evolution were established long ago. It was not to our credit that we continued to restrict their application as we taught them for half a century or more after their discovery. On the other hand, much of the fundamental material in physiology, the basic principles of heredity, our understanding of ecologic balance, of epidemics and of their control, most of the generalizations in distributional biology, and even the best of the principles in taxonomy, represent contributions of the last thirty or forty years. None of them is botanic or zoologic; all of them are applicable to both plants and animals.

Today, biology teaching can be unified by building around these broad principles. It is no longer a question of studying the structure of a grasshopper while we hold a dandelion in the other hand, but a matter of studying the fundamentals of processes for which the dandelion, the grasshopper, and any number of other organisms serve as specific illustrations.

AN EXAMPLE OF BIOLOGIC APPROACH

Physiology may provide an illustration of the possibilities of unifying a tremendous body of specific facts which are usually classified in two or more unrelated sciences. In the traditional course in plant physiology we have been considering such unrelated phenomena as photosynthesis, tropisms, growth, respiration, germination, fertilization, heat production, plant movement, plant foods, and transpiration. Rarely did the student perceive any systematic relation between the several processes, and usually he came from the course confirmed in his preconception that plants are physiologically the opposites of animals. One may find graduate students in botany who believe that heredity is a phenome-

non restricted to animals, and that there is something which in some way makes respiration in plants fundamentally different from that in the animal body.

In the course in animal or human physiology reflexes and nerve impulses, blood circulation, digestion, respiration, body heat, excretion, enzymes and vitamins, hormones, immunity, heart beats, and senescence—a score of processes are presented in no particular sequence and with no suggestion that plants indulge in a single one of these activities. As a result there are fourth-year zoology majors who are surprised to learn that evolution occurs in plants, and advanced graduate students in zoology who think that plants do not respire at all.

But the story of living processes may, for the most part, be presented as a single chain of phenomena which are strikingly alike for both plants and animals.

I. Foods are built:
   1. By photosynthesis, producing sugars and starch (these foods being built in plants for both plants and animals)
   2. By transforming carbohydrates into fats
   3. By building proteins (though the initial processes may be confined to bacteria, blue-green algæ, etc.)
   4. By utilizing minerals

II. Foods are transformed into living protoplasm:
   1. By digestion
   2. By assimilation

III. Foods and protoplasm are broken down (with a consequent release of the energy stored in them):
   1. By respiration (or by its modification, fermentation)
   2. By waste
   3. By decay

IV. The energy, released in the organism, produces:
   1. Heat
   2. Movement
   3. Light
   4. Electricity
   Etc.

All of the above phenomena are common to both plants and animals. In the few instances where a process is limited to a particular group, both plants and animals are dependent on that group for taking that step in the metabolic chain. All of the specific processes are links or episodes in the chain. It is fascinating as a picture of related events, a drama to capture the imagination of beginning students, a story which, because of its very orderliness, is simpler to grasp than the many details of the older presentation, a body of principles so broad that the student may acquire an understanding of an endless number of the specific things with which he will come into daily contact.

This is one illustration of the fact that the modern sciences provide a sound basis for unifying the introductory course.

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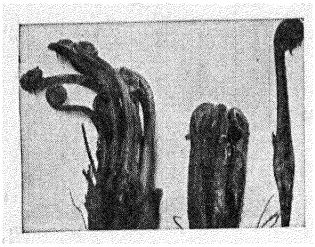
CHAPTER VII

THE TYPE, SYSTEMATIC, AND PRINCIPLES COURSES



THERE ARE THREE WAYS IN WHICH the materials of the introductory courses in botany, zoology, and general biology have been organized. These are the type, the systematic, and the principles courses. It might seem that any number of modifications or combinations of these three types could be made; but in actuality there are few textbooks, syllabi, or classroom programs which are not readily classifiable under one of these heads.

THE TYPE COURSE

The type course was the special contribution of Thomas Henry Huxley in 1879. Since the advent of morphology in elementary teaching, the method of the type course has been the one most often followed. Its prestige is still great.

In this course, the student studies a series of selected species which stand as the types of the various phyla and important classes. He makes dissections of the specimens involved; and, if Huxley's original idea is carried out, he is expected to find in each type an illustration of some more general biologic principle. An amœba stands for protozoan structure, but illustrates cellular physiology as well. A sponge shows the importance of the division of labor. A cœlenterate presents primitive nervous structures and, possibly, alternation of generations. The flatworm

stands for parasitic degeneration; the appendages of a crayfish for homologies and adaptations, and the frog for several vertebrate functions as well as for vertebrate structure. In the plant types an elaborate series of algæ, Marchantia, a moss, a fern, and a tulip are supposed to illustrate the development of sex, alternation of generations, and the nature of the seed.

The advantages of the type course:

1. It is primarily morphologic, and thus considered basic to an understanding of other aspects of biology.
2. The materials are tangible. They are specific structures to be discovered, observed, and drawn; technical terms to be defined and applied to the structures; actual material that can be touched and dissected.
3. The type course is, therefore, the best for teaching the scientific method. It instills respect for specific facts acquired by observation. This is an argument of considerable weight for the type course.
4. It is intensive. The student concentrates his studies upon a few species which are, in consequence, studied in considerable (morphologic) detail. There is something to be said for any force in modern education which tends to mitigate the superficial tendencies of present-day thinking and activities.
5. It is to some extent a survey course. The types show something about each and every one of the main groups of plants and animals.
6. Abundant laboratory material can be procured. There is no limit to the number of species that may be dissected.
7. The laboratory program has considerable teaching convenience. It demands little time in daily preparation. "Every autumn we lay in a few cans of soused dogfish and pickled sea-cucumbers, coop up some guinea-pigs, earthworms, cockroaches and fruit-flies, throw in a bag of beans and several bales of hay for the botanists—and we are prepared for the worst."[1] It does

[1] Wheeler, W. M. 1923. The dry-rot of our academic biology. Science 57:63.

not even demand the teacher's constant attention during the laboratory hour. By emulating no less a master than Louis Agassiz, we can set the students to their dissections while we go about our own business. It is a simple matter to procure laboratory guides which list enough technical names of structures to keep the student fully occupied. It is undoubtedly the teaching convenience of this laboratory which is primarily responsible for the high favor in which it stands *among teachers.* Especially in the secondary schools, where teachers may be burdened with six or more classes in a single day, teaching convenience is an item not to be ignored in the choice of a program.

Against the type course:

1. It is too exclusively morphologic. Morphology is not as basic to the other sciences as some would have us believe.

2. It often fails to interest the student. It may even kill what interest he has had in the subject. Making dissections, fussing over details of drawings, memorizing morphologic terms—these do much to dishearten the beginner.

3. It is not a real survey course. While it may offer examples of structure from numerous phyla and classes, it fundamentally ignores taxonomy, distributional biology, physiology, genetics, ecology, and behavior. Morphology constitutes only a small part of biologic science. In a morphology type course, the student never glimpses the great body of material which constitutes modern biology.

4. It is difficult or impossible to unify plant and animal matter in a type course. If we are interested in securing the best unification of biology, we cannot build the program entirely around the type course.

5. It is a poor means of teaching principles. It is not good teaching to show the student one specific instance and lead him to generalize. Teaching is hardly inductive unless it depends upon the utilization of numerous instances of a phenomenon. In actual practice, in the type course it is a rare student who perceives the principles supposed to be illustrated by the types. Of

those who have studied crayfish appendages how many can, offhand, still expound the homologies of the parts? And what conception of evolution can one derive from a study of those appendages?

6. Types are inadequate bases even for morphologic generalizations. There are many common insects that do not have the six legs, nine abdominal segments, and chewing mandibles of the grasshopper type. The most familiar crustacea (the pillbugs and the sowbugs) are far removed from the crayfish type. Not all vertebrates are built like frogs. And few of the families of flowering plants could be analyzed by a student who knew only a tulip.

THE SYSTEMATIC COURSE

This is a combination of the natural-history aspects of the older, systematic program with the type course. It deals with the natural history of the larger groups of plants and animals: insects, crustacea, spiders, clams, fish, amphibia, reptiles, birds, mammals, protozoa; algæ, fungi, mosses, ferns, seed plants. While each group may be introduced with a study of the structure of a single species which serves as a type, the program allows for giving considerable attention to the general biology of each group: its classification, its peculiarities of physiology and behavior, its economic significance, etc. There are introduced, therefore, many more aspects of biology than are included in the morphology type course. When the type course has seemed most successful, it is usually because it has been broadened into a systematic course, utilizing numerous species as types of each phylum studied. Some of the best of the current high school texts represent systematic courses in at least parts of their organization.

For the systematic course:

1. It is a natural approach to the living world. Before reaching the formal course in school, the native interests of many a boy and girl have led him to study birds, trees, flowers, or some other group or groups of organisms. Even among research stu-

dents, there is much to be said for considering all aspects of a single group, instead of passing its taxonomy over to the taxonomists, its morphology to the anatomist, embryologist, and cytologist, and its ecology to another specialist who knows little about its taxonomy, morphology, or physiology. Each aspect of an organism must be interpreted in regard to its other aspects, for it is, after all, a single organism, irrespective of the number of -ologies we call in to analyze it.

2. It actually interests young students. In the high school it is undoubtedly superior to the type course in this regard. The systematic course might well be given more consideration in the colleges.

3. It provides some introduction to several biologic sciences. Some aspects of taxonomy, morphology, physiology, ecology, and behavior may be studied in connection with each group. Distributional biology and genetics are not so easily included.

4. Emphasis on particular groups may be adjusted to fit local conditions and interests.

5. The materials are as tangible as in the type course. Ideally the laboratory may present many species instead of a single type from each group. In actuality, however, the laboratory in this course rarely differs from that with the type course.

6. It may represent sound inductive teaching. By utilizing numerous species in each group, it is possible to lead to fair generalizations about the group as a whole.

Against the systematic course:

1. In actual practice, it gives too much attention to morphologic material. It would be quite feasible, however, to shape the course into one which emphasizes any of the other aspects of biology.

2. It fails to unify botany and zoology. It comes more nearly doing so than the type course. It is quite in the spirit of the systematic course to study cross-pollination in connection either with insects, or with flowers; but the insects are still encountered in one part of the semester, and most of the material on flowers

in another, without the complete unification that a principles course could bring.

3. It deals with facts rather than with principles. It has been likened to a hypothetical program in which potatoes were studied one year: their arithmetic, their history, and their geography; while coal, its arithmetic, history, and geography came in a subsequent semester; and other items, their arithmetic, history, and geography in still subsequent periods of instruction.

4. It arrives, at best, at principles applicable only to particular groups of plants or animals. The focus of attention is, at any time, on the group and not on the principles. Although the course may arrive at generalizations applicable to mosses, to insects, to trees, or to other groups, such broad problems as the protoplasmic basis of life, the factors of distribution, ecologic balance, epidemics, heredity, and evolution must be considered in an appendage to the systematic course, if they are to be included at all.

PRINCIPLES COURSE

This program differs radically from either the type or the systematic courses. Instead of concentrating upon an intensive study of a limited number of types, or on taxonomic groups, it deals with principles applicable to large portions of the living world. It deals with such problems as reproduction; the development of the individual organism; the origin of food; its utilization in building protoplasm and accomplishing work; the regulation of animal activities by hormones and vitamins; disease and its control; the fundamental principles of heredity; contrasting influences of heredity and environment; the nature of individual variation and the origin of new species; chains and webs of ecologic relationships; epidemics; the maintenance of an ecologic balance; the bases of plant and animal behavior; etc. In illustration of each principle, an abundance of species, both plant and animal, may be utilized. The presentation of such a body of biologic principles was, as we have already shown, impossible a few decades ago, for biologists did not then have enough of the specific data to establish most of the principles that we

own today. The principles course is consequently a product of the modern expansion of biologic science, and in no sense a development of the type or systematic courses.

For the principles course:

1. Principles are master keys to unlock many doors. Thus equipped, the student may find an endless number of specific instances of the principles, as he travels the paths of life.

2. This wide applicability of principles makes them peculiarly interesting. Given some understanding of heat production in destructive metabolism, the student finds new significance to the heat produced in the opening of the flower, in the decaying mass of manure, in the mound nest which serves as an incubator for the ant, in the movement of his own human body. An endless list of familiar items are built up into an ordered science. The discovery of a new instance of a learned principle may bring each boy or girl the thrill of exploration. Experience shows that principles are highly effective devices for interesting students.

3. Principles *are* practical. Although specific facts in applied, economic, or civic biology fit the particular situations learned, few elementary students are able to see the same problems involved in very many of the new situations which they meet. But when the emphasis has been on principles, and when the student has been given especial practice in making applications of principles, he should subsequently be able to apply them in any number of other cases.

4. The principles course provides the best basis for unifying botany and zoology. Emphasis, in a principles course, is continually on the common bases of plant and animal activities. There is no other program equally effective in unifying the study of the two kingdoms.

Against the principles course:

1. Principles are too intangible for beginning students. It is questioned whether boys and girls of high school age, or even at the college level, can really understand and apply principles.

The answer to this objection is, however, that during the past ten years thousands of teachers in the secondary schools have been using programs built around principles, and their experience seems to indicate that average teachers *can* make principles effective for beginning students. But this is more likely to be true with tenth-grade instead of ninth-grade classes, because of the much larger number of pre-adolescents in the lower class.

2. The use of principles operates against the development of respect for facts obtained by observation. Students trained in principles are inclined to talk generalities, to despise specific details, and to avoid the trouble of making specific observations. When this happens, the course fails to attain one of its chief objectives, namely that of inspiring boys and girls with respect for the scientific method. This would, indeed, be an unfortunate outcome of a principles course. It should, however, be possible to teach principles and still to develop respect for observed data, by demanding that the student become familiar with numerous specific examples of each and every principle involved.

3. It is questioned whether a laboratory program is available for a principles course. The classic laboratory is in morphology and physiology. In many college and university courses the lectures and recitations deal primarily with principles, while the laboratory follows a morphology type course. What is needed is a laboratory that will provide specific instances of a large variety of the principles in each and every field of biology.

Teachers have been peculiarly slow to realize that there is effective and worth-while laboratory material in something other than plant and animal dissections. This is another result of the domination of the college courses by morphologists. But, in actuality, there is good and easily taught material available in taxonomy, distributional biology, genetics, and behavior. Beginners are capable of understanding that the materials used are specific instances of the great body of data from which the broad generalizations, the principles, have been derived. Such a laboratory program is outlined in Chapters XVII to XXIII in the present volume.

CONCLUSIONS

The success of any method in teaching depends primarily upon the skill of the teacher. Effective teaching of biology has been done many times by many teachers in each of the three methods discussed above. A capable teacher will succeed with any method that he believes in. Methods that work in the hands of one teacher may fail when employed by the next. It would be presumptuous to suggest that any particular type of course is the best in biology.

There are sound arguments for each of the three programs outlined above. The type course provides the most tangible material, an especially effective means of demonstrating the scientific method, and the most convenient laboratory. The systematic course finds its soundest arguments for existence in the natural bases of its organization, and its evident interest for beginning students. Principles, on the other hand, in providing keys for interpreting specific facts, and sound bases for the unification of botany and zoology, furnish material not available in the other programs.

It would seem ideal to develop a teaching syllabus that combined the good points of each course. In actual practice, this seems never to have been achieved. A program of lectures on principles with laboratory work on types does not represent a combined course, but two separate courses which, by their very divergence, confuse the student. The inclusion of a few chapters on principles in a textbook which is essentially systematic seems to contribute nothing to the effectiveness of the teaching.

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CHAPTER VIII

THE RESTRICTED AND THE SURVEY COURSES

UNTIL THE BEGINNING OF THE PRESENT CENTURY, there was, as we have already noted, little biologic science outside of systematics and morphology. With the rise of the several newer sciences, it becomes necessary to decide whether the introductory course shall continue to be restricted to morphology or to some other single science; or whether the introduction should be a survey, including a pre-view of several or all of the biologic sciences.

THE RESTRICTED COURSE

A half century ago the beginning course, both in the high schools and in the colleges, was usually concerned with systematic botany or with systematic zoology. Since the turn of the present century, restricted courses designed for elementary students have, in almost every case, been courses in morphology, or in physiology, or a combination of the two. The other biologic sciences are presented in restricted courses only when designed for more advanced students. The arguments for and against the restricted course as it is used for beginners are considered in the following discussion.

For the restricted course. Since the restricted course is usually morphologic, it may embody some of the merits and faults of the morphology type course (see the preceding chapter). To repeat these points, the restricted morphology course may be defended because:

1. Morphology is said to be basic to the other biologic sciences. This significance of morphology is, however, open to question.

2. The materials are tangible.

3. The restricted morphology course is, therefore, an effective means of teaching the scientific method (respect for specific data obtained by observation).

4. It provides a laboratory program particularly convenient for teaching.

5. It inspires respect for thorough studies. In a day of tabloid newspapers, radio, moving pictures, and other pre-digested instruction, it does seem that somewhere in our educational scheme we should impress students with the importance of the thorough mastery of one field.

Against the restricted course:

1. The restricted morphology course too often fails to interest students.

2. Morphology is not as rich in general principles as some of the other biologic sciences. If the restricted course were given in some other field, it might center about the principles of the science, but that is practically impossible in morphology.

3. In the restricted morphology course, there is very little basis for the unification of botany and zoology.

4. The restricted course fails to give the general student a balanced picture of modern biology. It fails to introduce many things which might contribute to one's enjoyment of the world: taxonomy, distributional biology, genetics, ecology, and behavior. These other fields are particularly rich in material of everyday import for the average man.

5. The restricted course fails to give the student, who will continue with advanced work in biology, the orientation which the specialists so badly need in this day of an expanded science. For this reason it is inadequate as an introductory course even for those who are to become professional morphologists.

THE SURVEY COURSE

In this program, some material from each of the modern biologic sciences is included. Since the interest centers about the more important materials in each of the sciences, the survey course is almost of necessity a principles course (see Chapter VII).

For the survey course, it is thus to be repeated that:

1. The principles of the several biologic sciences may unlock the door to innumerable specific facts.
2. This wide applicability of the survey course makes it unusually interesting to the student. In the restricted course all students must find their interests in the same phase of biology—or leave without ever finding the subject matter interesting. Somewhere among the several biologic sciences which are included in a survey course each may find material of particular concern to him.
3. The survey course, because it deals with principles, provides a sound basis for unifying botany and zoology.
4. For the average man, a survey of the whole field provides the best basis for his further contact with biology. The beginning student is a tourist, unaware of the extent of the world, its endless treasures, its diverse interests. They are poor guides who ask him to spend all of his first sojourn in the intensive study of a small portion of the landscape, to forget the forest and concentrate on a single tree, to ignore the mountain and spend the time in exploring a single canyon, to ignore the canyon and examine only a single layer of rock in it. There is much to be said for surveying a large section of the landscape before concentrating one's attention on a single item in it. The average citizen needs to have some notion of the latitude and longitude of a wide number of the biologic items which he may meet in later life. He should then be able to realize that particular questions are, for instance, problems in physiology; that others are problems in economic entomology, genetics, or behavior; and that others have been subjected to investigation by specialists in still others of the several biologic sciences.

5. Similarly, a survey of the whole field provides the best basis for a more intensive study of a portion of it. This is an argument for presenting a survey course to students who are biologists in training. In a day when research workers must become specialists in very limited ends of the science it seems particularly important that the professional student should have a broad introduction to the several fields of the whole science. Else our graduate schools will continue to breed ecologists so ignorant of taxonomy that much of their ecologic research is invalidated by inadequate taxonomic determinations; geneticists who discuss the origin of an entity (species) with which they have had no contact; taxonomists who do not know that genetics has contributed anything to the evolution problem; comparative anatomists and physiologists who have no conception of individual variation; students of behavior (including psychologists) who have never examined the geneticist's data on the inheritance of acquired characters; and paleontologists who record orthogenesis without knowing of fundamental contributions in biologic evolution. Among all the problems facing the university that undertakes the training of research biologists, this is one of the most strategic. The day is past when future botanists can be trained by teaching them from a text in plant anatomy which relegates genetics to a footnote containing nothing but a statement that "this is another field of biologic investigation which has attracted some workers."

Investigators need to learn what the materials and problems are in fields other than their own. They must acquire such respect for these other fields that they will call upon them for help when their problems lead in those directions. The institution which is training specialists in this broad way is preparing the leaders among the research men of the future.

Against the survey course, it has been objected that:

1. It is superficial. It covers so much ground that it does not adequately equip the student for understanding anything. But it is to be noted that superficial and thorough are only relative

terms. The cell studies presented in an elementary type course must seem very superficial to a cytologist. The systematic botany included in any beginning botany course is certainly superficial as compared with the work of a research taxonomist. It is not easy to determine how much of any subject must be included in a beginning course in order to make the instruction something more than useless or pernicious. Some teachers believe that they can make an adequate presentation of the elements of a half dozen or more of the biologic sciences in a year's course. It is necessary, however, to avoid the inclusion of more material than the student can really master in the available time.

2. The survey course demands too much knowledge on the part of the teacher. This, however, is merely an admission that training courses for teachers have given them little of anything but morphology and physiology. Instead of devoting twenty or thirty hours to course work in the morphologic sciences, they might well have included systematics, physiology, genetics, ecology, and still other things in their training.

REFERENCES: RESTRICTED AND SURVEY COURSES

*CHANDLER, E. 1906. The relative emphasis to be given physiology, morphology, ecology, and other phases of botany and zoology. School Sci. & Math. 6:393-397.

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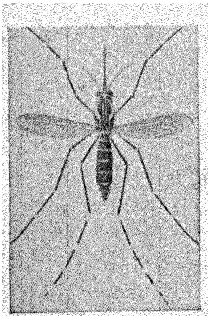
* Recommended as the best reference for student use.

CHAPTER IX

PURE VERSUS APPLIED SCIENCE



IT IS A QUESTION WHETHER THE INTRODUCtory course should be built upon such pure science as may concern the research student; whether it should try to win interest and make contacts with the lives of everyday men and women by restricting the content to items of known economic significance; or whether the two viewpoints may in some fashion be combined in an elementary presentation.

Many scientists are prone to mistrust and disdain all attempts to apply the findings of research; but many educators feel that much scientific teaching is ineffective because it fails to relate to the practical needs of the average citizen. There is undoubtedly something to be said for each viewpoint.

FOR PURE SCIENCE

The advocates of pure science in the elementary course contend that:

1. The history of science proves the economic importance of basic principles. Many of the most important applications of science have been derived from discoveries which, at the time they were made, had no conceivable practical significance. In biology, Mendel's curiosity about hereditary characters in peas, combined with the long labors of the students of the structures of cells, founded a science which is revolutionizing plant and

animal breeding. It is settling the age-old question of the relative significance of heredity and environment, and is providing specific data upon which the intelligent control of human heredity may ultimately be based. The amusements of the early possessors of lenses were the beginnings of such sciences as cytology, histology, and bacteriology, and these are the foundation for much of the practice of medicine. The studies of insect classification, behavior, and life histories are at the base of the modern program of insect control. History abundantly justifies the scientists' contention that anything true is worth discovery.

But to what extent this is an argument for pure science in a beginning course designed for average future citizens is not so directly apparent. Scientists too often overlook the fundamental objectives of elementary teaching.

2. Given the principles, one may readily make the specific applications in economic fields. This is the defense which we have already found for any principles course. Given a basic understanding of animal structure and the fundamentals of metabolism, one has a sounder basis for shaping the use of his own body than he would have if equipped with nothing but the pre-digested dicta of the textbook in hygiene. Given a basic understanding of plant structure and physiology, one may more readily acquire the practical experience necessary in the management of a garden or small farm. Students trained in the applied sciences alone find it difficult to extend their experience beyond the particular instances to which they have had an introduction.

3. Pure science commands wider interests than applied science. Many things which have no dollars and cents value may contribute materially to one's enjoyment of the world. Some knowledge of the classification of the plants and animals one may meet, an insight into the meaning of the life zones through which one travels, and some understanding of the behavior of the insects that cross one's path are, in the enjoyment they bring, as important as a knowledge of civic sanitation or of the best methods for killing ants in a pantry.

4. The applied sciences too readily accept procedures for which there are no sound scientific bases. Much of the material

that passes for applied science is a "species of toothbrush biology suspiciously fortified with the trappings of personal faith." As we have pointed out elsewhere, the texts with an economic or civic program include "extended exhortations on wasting foods in kitchens, on coffee, tea, cocaine, candy, tobacco, Keeley cures, ventilation, garbage disposal, artificial resuscitation, vegetarianism, whole chapters on vaccination, and the latest gospel on vitamins, pages on constipation, woolen underwear, and Freudian complexes." Much of the material so presented is merely an exposition of the current mores, often with little or no science involved, if indeed it is not directly contradictory to the scientific data. One generation objects to the drinking of water at meals, the next finds the same procedure acceptable. The widely used "experiment" in which a fresh egg is broken into alcohol in order to "demonstrate" the harmful effects of the latter substance, has as much science in it as the slight of hand of an Oriental juggler. The classroom use of the slogan that "a clean tooth never decays" merely evidences the inability of some teachers to distinguish between scientific authority and the high pressure salesmanship of big business. Even the daily bath, whatever its esthetic attraction, cannot be defended on scientific grounds. Careful scientists are wary of too much application of science by poorly qualified teachers and beginning students.

FOR APPLIED BIOLOGY

1. Practical applications in any field of knowledge are certain to arouse the interest of the average student and citizen. The more pertinent the applications, the more certainly do they command attention. The city boy is particularly interested in the biologic problems that affect him in his city environment; the country boy, in the biology of the farm. With an endless amount of practical material available, why should the introductory course go beyond civic or agricultural biology? Why should the entomology course be anything but economic? Why should genetics center on anything but human genetics and eugenics?

Why should physiology be anything but human hygiene, or bacteriology?

2. The practical value of any subject is its chief justification. This is a practical world, and many teachers as well as parents and legislators are inclined to consider training for an occupation as the prime end of both secondary and college education. While we have already expressed some disagreement with this viewpoint, it is very certain that one who presumes to expend public funds for anything that can show no immediately practical results must be ready to defend his position.

The issue is one which concerns not only the introductory course in the high school, but many of the advanced courses in the colleges as well. The universities have to face the question of one biology for prospective biologists, another for general students, one for home economics majors, one for those in physical education, and another for agricultural or pre-medical students. The Commission on Medical Education (Capen 1929) believes that there has been a harmful tendency toward a too early presentation of details in the training of both pre-medical and medical students, and urges that those sciences be presented first in a more comprehensive way. In accord with this attitude, the deans of some medical schools recommend only the broadest sort of general biologic training for pre-medical students; but others would restrict them to courses in comparative vertebrate anatomy, and to embryology with an emphasis on organology.

COMBINING PURE AND APPLIED SCIENCES

It is obvious that the arguments given above are, for the most part, well taken on both sides of the issue. There is little to be said for the pedantic attitude, too often assumed by research students, which brands all practical applications as undignified. But the restriction of the introductory course to matters of economic importance produces an unbalanced structure not adapted to serve as the foundation for further learning.

It is a simple solution of the problem to combine the two viewpoints, basing the course on the principles of pure science,

while making as many practical applications of those principles as time allows. While putting genetics on its Mendelian basis, there can be no excuse for ignoring its application to human heredity. Ecology should begin with a discussion of its broadest principles, even though ultimate interest may be in the economic aspects of the subject. The fundamentals of physiology are the best possible bases for the consideration of balanced diets and vitamins, of the significance of the endocrine glands, or the control of disease.

Happily, this reconciliation of extreme views is spreading in much of our education today. The agricultural and engineering schools are liberalizing their basic courses; the liberal colleges are becoming more professional. The purely economic zoology, economic botany, or civic biology which attracted the secondary schools a decade ago is largely replaced by more balanced programs; everywhere agricultural courses are turning to a more general biology for their background. Even the over-emphasis on human hygiene, although fortified in several states by laws requiring its inclusion in the biology course, and recently supported by departments of physical education seeking positions for their graduating athletes, seems to be giving way to a wider interest in the basic sciences.

The colleges are the schools that are still most extreme in their use of pure science. Even here, however, there are indications (for instance, such a recent text as Snyder's in Genetics) that the colleges are trying to relate their sciences to the lives of their students.

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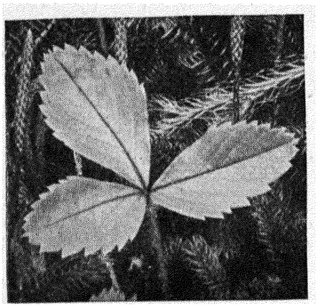
CHAPTER X

THE ORGANIZATION OF UNITS



THE UNIT METHOD IS AS OLD AS the first teacher. It is as familiar as the preacher's "firstly" and "secondly," and it has had no magic added by its rediscovery and rechristening in modern pedagogy. Its scientific basis is common-sense psychology familiar to many a soap-box orator whose arguments are presented without benefit of degrees but with an effectiveness that we, as teachers, might profitably study.

The Oxford Dictionary defines a unit as "a single individual or thing regarded as a member of a group," and as "one of the separate parts or members of which a complex whole or aggregate is composed or into which it may be analysed." The term may be applied to any subdivision of the whole which is essentially complete and independent, but contributary to the whole. In brief, it is a separate topic which has a real bearing on the main subject.

In recent years there has been an attempt to restrict the term "unit" to a particular method of pedagogy, and, in biology, to particular topics which have particular objectives. It has been insisted that "a unit in biology should be focused on some major life-process or activity, or on a group of closely related life-processes and activities." Although we may be in hearty sympathy with the extended use of physiology in elementary teach-

ing, there is no justification for restricting the use of the word to physiologic units.

It is further urged for the new type of unit that it "must contribute to an understanding rather than give a descriptive account" of the subject. This statement obviously does not express the opinions of a student of such descriptive sciences as biology, geology, or astronomy.

The further restriction of the term to those units which "permanently modify the pupil's attitude and affect his behavior" is at least an optimistic use of the term.

CHARACTERISTICS OF A GOOD UNIT

A good teaching unit may be described as follows:

1. **It is concerned with a single subject.** Algæ, Genetics, Insect Mouthparts, Feeding Processes in Animals—these units are all satisfactory from this standpoint. But a unit on "Organisms in Relation to Man" should not involve (as it does in one text) a treatment of eugenics. The inclusion of more than one subject in a single unit asks the student to see a relation which does not exist, and interferes with the concentration of his interests and with his efforts to master the unit.

2. **Each unit should be obviously distinct from other units.** It should not require too much explanation to make clear that the materials, objectives, or methods of the one unit differ from those of the next. The units in some of the current texts are so vaguely defined that even a professional biologist would encounter difficulty in discovering the bases on which the division is made.

3. **A good unit is pertinently labeled.** As a handle by which the student may constantly hold to the ideas inherent in the unit, the title is best when short and unmistakable in its meaning. Birds, Growth in Plants, Reproduction, Life Processes, are good titles. As a title, the name of a unit is a noun or substantive phrase. The authors of some of the texts seem never to have tried to diagram such astounding phrases as "How does

man provide favorable conditions and necessary materials for living things?" or "How are living things related to their physical surroundings?" The current fad for casting all titles of units and the legends for text figures in the form of questions reminds one of syncopation which, unusual when used with restraint (as in a Beethoven Symphony), may become monotonous and ineffective because of its endless use in modern jazz. Even if declarative or interrogative sentences were convenient handles for grasping a unit, their repetitious use makes them ineffective as means of startling the students into response.

4. **There should be an obvious relation of each unit to the subject as a whole.** This should be apparent both to the teacher and to the beginning student. It is a chief objection to survey courses that they so often fail to show the relation of the parts to the whole. This is an objection to the divided course in biology, with its separate treatment of botany and zoology. This is a chief objection to "general science" which, worthy as its aims may be, appears to most beginners as a procession of unrelated topics. In order to build a group of units into a sound whole, the material of each should provide an introduction to the next unit. Continual reference to the objectives of the subject as a whole should also serve to coordinate the units of which it is built.

5. **The size and the number of units should be carefully determined.** A unit should be neither too large nor too small a portion of the whole. Too large a unit is not easily comprehended, and such a unit becomes so important as to hide the significance of the whole. If, on the other hand, there are many small units, it is difficult for the student to keep them all in mind. The sermon with a dozen points is as ineffective as the one that has no subdivisions. Four or five topics are enough for a single lesson, and five to seven units enough for a year's course. A unit which covers five or six weeks of work seems good for beginning students in the secondary schools. In one-semester courses the number of units may be reduced, and the treatment of each (especially in the colleges) may demand less time than is given each unit in a full year's course.

TYPICAL UNIT ORGANIZATIONS IN BIOLOGY

One cannot escape the feeling that the desire to appear original rather than any sound understanding of units accounts for the many plans of organization which are to be found in biology texts. There are, however, three schemes which seem to find a natural basis in the materials of the science. These are the systematic, the type, and the methodological programs which have already been mentioned (Chapter VII).

Systematic organization. The simplest—and a formerly much-used, organization depended on the classification of the plant and animal groups. Several texts are still built on three such units:

The Plant Kingdom
The Animal Kingdom
Human Biology

These three units give a divided course (see Chapter VI). The first two are independent parts of the whole, but the third is not logically distinct from the second. Moreover, there are not enough units for good teaching.

The following selection of the more common and interesting groups may be considered a better arrangement for beginners:

Plants	Animals
Algæ	Protozoa
Lichens	Sponges
Mosses and Liverworts	Worms
Ferns and Fern Allies	Insects
Conifers	Spiders
Monocotyledons	Snails
Dicotyledons	Fish
	Amphibia
	Reptiles
	Birds
	Mammals

A well-developed systematic program which rises above the old morphology type-dissection course and includes the diverse biologic aspects of each group is, strange to say, not to be found in any of the current texts; but its beautifully sound unit organization made it the basis of many courses in the natural history period, and its use may be expected again in some future day.

The type course. (See Chapter VII.) The units in this course are almost as natural as those in the systematic course. The major defect in the type course is its apparently necessary preoccupation with morphology, and not in the choice or order of its units.

Methodological organization. The units here are the sub-sciences of biology. They are:

Taxonomy
Distributional Biology
Morphology
Physiology
Genetics
Ecology
Behavior

This is a methodological organization because each sub-science represents a method by which biologic phenomena may be observed and analyzed. The geneticist, for instance, compares individuals of successive generations; the taxonomist compares species and higher groups of organisms; the morphologist tries to explain things by analyzing their structural bases; the physiologist looks for the bases of those same biologic entities in life processes. There are subdivisions of many of these sciences. Morphology, for instance, includes gross anatomy, histology, cytology, embryology, neurology, osteology, etc.; physiology includes nutrition, endocrinology, etc. There are also some sciences, like bacteriology, entomology, ornithology, etc., which have a systematic basis and which are fusions of several methods; but practically all of the materials of biology can be classed under one of the seven heads listed above.

The units as listed represent about the only methods which scientists have used to examine living matter, and additional units cannot be found until biologists create new techniques for analyzing nature.

Inasmuch as both plant and animal phenomena contribute to the body of data in each of the seven sciences listed above, the methodological organization is well adapted for the presentation of a unified biology course. It is almost necessary that such a course revolve about principles. And in the presentation of the complete list of biologic sciences, one has a survey course which has proved quite practical for beginners.

Artificial units. These are artificial in the sense that they are inventions of the human mind. Such units are sometimes logical, and sometimes effective in teaching, but often they are so artificial that the student cannot understand their limits and their relations to the whole. The number of ineffective, artificial units in current texts and syllabi is increasing at an amazing rate under the stimulus of educational seminars and teachers' institutes.

Such artificial units as the following seem to be pedagogically sound and effective:

Human Diseases and Their Control
Adjustment to Environment

The next lot includes units which are so vaguely labeled and defined that one has difficulty in anticipating their content and, while studying the unit, similar difficulty in keeping the central point in mind:

Changing Forms of Living Things
How Do Living Things Maintain Their Kind?
How Are Living Things Improved?
The Development of Organisms
Life Activities of Animals
The Struggle for Energy Through Succeeding Generations

The materials of the following units seem very arbitrarily limited, and without any natural basis to establish their pedagogical value:

The Fascination of Microscopic Life
On the Trail with Camera, Rod, and Gun
How Does Man Provide Favorable Conditions and Necessary Materials for Living Things?
The Control and Improvement of Organisms
Improving Methods of Using and Conserving Energy
Classification of Plants and Their Relation to Their Environment

SEQUENCE OF UNITS

The factors to be considered in determining a sequence of units are these:

1. **Factual relation.** Some units contain material which must be mastered before another unit can be understood. Thus, an understanding of the morphology of cells and of the physiology of reproduction is prerequisite to an understanding of heredity. There are other instances of such logical sequences which are too often overlooked in teaching. On the other hand, this point is sometimes over-emphasized in college courses; morphology is not the basis of the other biological sciences; and one does not need to have a detailed knowledge of classification before he can understand evolution.

2. **Difficulty of comprehension.** The simplest unit should come first, the most difficult should be delayed as long as possible. Units involving protozoa and algæ, although logical as starting points, are too difficult for a beginner to handle. It is, of course, true that whatever the content of the first unit, it will always seem the most difficult to a beginner. But it is still possible to start with a unit which will cause less trouble than some others.

3. **Interest.** There is an art in building a semester's course. Like a good story, it should begin and end with a bang. In

between, it should have high spots so distributed that interest will not flag. Each teacher should begin and end the semester with a unit that he can handle with considerable enthusiasm. It is particularly important that the last unit be so interesting that the students will regret the conclusion of the year's work.

4. **Seasonal availability of material.** This is a prime consideration in all regions which have a winter season. Some units (*e.g.* taxonomy and behavior) are quite ineffective when taught without fieldwork or live material for laboratory use, and they must therefore come in the early fall or late spring. There are some units (*e.g.* morphology, genetics) in which preserved material may be used in the laboratory, and they may be presented in the winter when some other units are not as effective.

As an example of the coordination of these diverse considerations, note the sequence of units in the following methodological course. It is planned for two full semesters which extend from early fall to late spring.

1. *Taxonomy.* September-October. It is simpler than some units and has considerable appeal if taught with fieldwork. But the fieldwork demands the position of the unit in the early fall or late spring.
2. *Distributional Biology.* October-November. A logical development of taxonomy. It can be taught indoors.
3. *Morphology.* November-December. Not interesting enough for beginning the semester; prerequisite to genetics; can be taught indoors, with little need of fieldwork.
4. *Physiology.* December-January. Would make a logical and interesting first unit, but too difficult to place so early in the course; can be taught in winter with a minimum of fieldwork.
5. *Genetics.* February. Must be preceded by morphology. The most difficult of all the units, but very interesting to beginning students; can be taught in winter with a minimum of live material.
6. *Ecology.* March-April. Little logical relation to other units, and effectively placed almost anywhere; placed here because its fieldwork does not demand more material than is available in late winter and early spring.

7. *Behavior.* April-May. Effective as a final unit because of its great interest when effectively taught. But this demands extensive use of such live material as is available only in early fall or late spring.

Rearrangements of the above would be possible in some southern localities where seasonal factors are of less importance, and necessary on the Pacific Coast, where the school year does not coincide with that found in the rest of the United States.

For half year courses, it is not possible to make as satisfactory a sequence of the seven units.

In full year courses beginning in the second semester a considerable rearrangement of these units would be necessary; and all efforts at such a rearrangement have proved so unsatisfactory that one is led to doubt the wisdom of beginning such a year's course in the middle of the school year.

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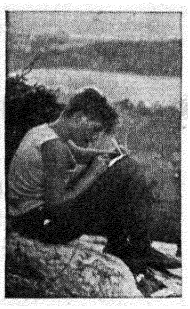
CHAPTER XI

BIOLOGY TEXTS



IT HAS BEEN SAID THAT TEXTBOOKS ARE SOLD and not chosen. The sales arguments range from the style of the binding and the display of educational fads to bribes offered those responsible for city or state adoptions. The published records of the Federal Trade Commission are some indication of the extent of this practice.

While most educators would deplore such methods, there seems little recognition of the fact that the individual teacher is often responsible for the entry of politics and graft into textbook adoptions. There is evidence that most of the publishers would welcome an opportunity to sell books on the basis of their intrinsic merits; but too many teachers are either not interested in the real quality of a text, or unable to judge whether it embodies the objectives, organization of subject matter, and effective presentation which they, the teachers themselves, might be interested in having.

The system of state adoptions of single texts is, fortunately, limited to a few states; and in them, usually, to smaller school systems or to subjects older than biology which, because of its recent advent, sometimes escapes the operation of the adoption laws. In most states the superintendent of the local system is responsible for the choice of texts; often he follows the recommendation of the high school principal, often of the biology teacher or, in school systems with more than one such teacher, of a committee of biology teachers. The beginning instructor is,

with some reason, more than likely to have his text chosen for him. After a few years' experience the individual teacher is directly or indirectly given the responsibility for the choice. The quality of the books in actual use then becomes a measure of the teacher's ability in choosing books—or in letting the books be sold to him.

IMPORTANCE OF THE TEXT

In the secondary schools the organization of the biology course has depended largely upon the organization of the adopted texts. It is probable that the books will continue to determine the content of the courses. The better books are the products of years of study by specialists to whose individual experience there may ultimately be added the experience of thousands of teachers who have used the text. Local or state syllabi rarely represent more than a few weeks' study, or, at best, a single summer of post graduate work.

A beginning class cannot use a syllabus that departs very far from the available text. Students in the secondary schools are too young and inexperienced to use lesson notes, or blackboard or mimeographed outlines as substantial substitutes. The use of multiple references in place of a single adoption is largely a development of the economic depression; and it is yet to be proved whether the coordination of the diverse treatments and often conflicting viewpoints of several texts is feasible with young adolescents, even though it may have its advantages with college students. A compromise may be effected by using a single adopted book while making a wider use of secondary references on special topics.

With the content of the biology course thus dependent on the text, it becomes doubly important that those responsible for the adoption be aware of the real nature of the book that is chosen. Considering the diversity of methods and materials that may be used in teaching the subject, it is to be expected that different teachers will find different books adapted to their needs; but this makes it all the more important that the adopted text embody

what the teacher conceives to be the most important things in an introductory course in biology.

BASES FOR CHOOSING TEXTS

Score cards for judging books pretend to mathematic accuracy in a matter which so largely involves individual evaluations that they are misleading. Therefore, while we shall discuss the questions involved in choosing a biology text, we do so with the understanding that each teacher will have to make his own evaluations of the items listed below.

1. **Aims.** The aims involved in a text are best determined by a study of the actual content, organization, and method of presentation of the material in the body of the book. Statements in the preface may provide a short-cut to the author's intentions, or they may conceal his inability to accomplish what he considers important or currently fashionable. But by examining the table of contents and by carefully reading groups of pages or whole chapters scattered through the book, one may better judge the real aims of the author and the extent to which he attains his ends.

2. **Content.** In as rich a field as biology, the effectiveness of a text will depend to a great extent on the selection and organization of the material. The available books are rather readily classifiable under the heads already studied (Chapters VI to IX):

A unified *or* a divided course
A type, systematic, *or* a principles course
A restricted *or* a survey course
A pure *or* an applied science, *or* some combination of the two

A text may be more efficiently used if it does not depart too widely from the teacher's idea of how the course should be organized as regards each of these problems.

3. **Style.** Next to the question of content, the question of the style in which it is written seems the most important in the choice of a text. Is the style clear? Is it readily understandable to the beginner? Is its vocabulary simple, its sentence construction comfortable? Is it direct in statement? Does it hit the nail on the head, or become hopelessly involved in its explanations?

Is the style interesting? Does it show an appreciation of student viewpoint, and effectively utilize a variety of devices for obtaining the student's interest (see Chapter II)? Can it, consequently, command the attention of the student? It *is* possible to combine scientific accuracy and attractive writing. It is not too much to ask that the student be interested in the daily assignment, even to the extent of wanting to read ahead of the class. Too many texts display facts but are badly written. The college texts average but poorly on this score. Many of the high school books are more lucid, and some of them are attractive in style.

4. **Organization of units.** Do the major divisions of the book satisfy the demands for good units: are they relatively few in number, is each concerned with a single subject, is each obviously distinct, are they pertinently labeled, logical in sequence, reasonable in length, and seasonably adaptable in the particular community (see Chapter X)? And yet, is the organization so evidently natural that one's attention is not distracted by the grinding of the educational machinery?

5. **Authority.** As scientists, and as teachers interested in teaching the scientific method, we are naturally concerned with the scientific accuracy of a text.

What is the scientific training and what are the present scientific contacts of the author? This may to some extent be judged from the biographies in such volumes as *American Men of Science,* and the various *Who's Who's,* from his present institutional connections, and from the evaluation of his work by others in the same field.

Participation in scientific research is one measure of an author's qualifications. That it is not the sole qualification is evidenced by the number of poor texts written by research men. On the other hand, all the pedagogical background in the world

cannot substitute for first-hand contacts with the materials and methods of the science in which the author presumes to write.

Has the author utilized the cooperation of experts? No single person can have had first-hand contacts with all the material that should be included in an elementary science text. Research scientists should have been called in to verify the several parts of the book, while experienced teachers should have contributed to its pedagogical set-up.

Has every effort been made to eliminate scientific inaccuracies in the book? It is, of course, to be understood that the simple generalizations necessary for beginners cannot always allow for the numerous exceptions known to older students; and it must be recognized that there is often room for diverse interpretations of the available data. But there is no excuse for the many errors of fact which occur in some of the elementary texts.

What is the teaching experience of the author? Experience with the problems of teaching has something of the same importance for an author as first-hand contact with the subject matter. Experience, however, is not to be measured by the author's age, for one's ability as an artist may, and often does, degenerate with the progress of the years. Many of the college texts suffer because they are the valedictories of older men who thus close up their life-times of experience.

To what extent does the author's teaching experience limit his authority to write for a particular educational level? This question has been the subject of some debate. On this point it is to be noted that there are four high school biology texts which, by their wide usage over a significant period of time, seem to be those generally accepted as the best. Two of them are written by men whose experience has been chiefly in the colleges, and two by men whose experience was chiefly in the secondary schools—but all four of these men have had experience in both the secondary schools and colleges.

6. **Date of publication.** Yearly models are as fashionable but as unnecessary in textbooks as they are in automobiles or hats. The school-man's use of the date of publication has little relation to the scientist's use of dates for judging the background

of a research paper. There are books with 1935 dates which contain less modern material than some which were first published ten or twenty years ago. It is also to be noted that a publisher may take advantage of this desire for the "latest" text by placing the printing date in a conspicuous place on the title page, while the legally required copyright date is put in small type on an inside page. Even new copyright dates may be secured without making significant changes in an old book.

7. **Teaching devices.** The items listed below include the best of the devices which may add to the teaching value of a book:

Amount of material included. A text should provide ample material for a full year's work, but the book should not be encyclopædic. However, a text must include more than enough for any one teacher if it is to provide a choice of material adaptable to particular communities.

Local adaptability. The diversity of biologic conditions in different parts of the United States calls for the use of eastern and western, northern and southern plants and animals in illustration of each of the phenomena presented in a text. Until ten years ago, the best books had all originated in the northeastern corner of the country, and reflected local viewpoints which were often meaningless to those in other parts of the United States.

Text figures. Illustrations in a science text provide a means of interesting the student, while contributing to his store of scientifically acquired information. In both of these connections, a well-chosen figure often has more value than a page of print. Half-tones are so much nearer reality that there is, in this day, no excuse for the use of line drawings for anything but diagrams and charts.

Glossary. A glossary is a desirable teaching aid in any subject which has as technical a vocabulary as a science. The glossary should be critically tested to see if it is understandable and attractive to beginners. If well done it may provide material for review, as well as for daily reference use.

Review questions. These are the most expensive of the current fads. A normally good teacher should be able to make questions that are more penetrating and pertinent than those that can

be put onto the printed page. Some of the elementary books have their text reduced at least one-third by the abundant review and new-type tests in them.

New-type tests. The significance of these is discussed in Chapter XVI of the present volume.

Problem questions. Problem questions, involving an original application of biologic principles to specific instances, may constitute an effective means for teaching scientific method, as well as for a review of principles learned. The development of a good set of such questions is much more difficult than the building of factual review questions, and the busy teacher may welcome their inclusion in a text.

Summaries. The chapter subdivisions and key sentences of the paragraphs in any piece of good writing should provide the bases for review. Something is to be said for having students learn how to analyze what they read without depending on a published outline. Nevertheless, many teachers want a review outline at the end of each chapter.

Index. An index should be full enough to include references both to general topics and to specific material. To avoid more than two or three page references under any single head, there should be subdivisions of the main topics in the index.

8. **Mechanical structure of the book.** The binding should stand reasonable wear. An attractive binding may favor the development of student interest. The type should be clear, well-inked, and easily read (but there is no current biology which is so poorly printed that this item is involved in the choosing of a book). The paper may be white, to secure contrast, or tinted to reduce light glare. The book should not be so large or heavy that it is inconvenient to carry. The prices of comparable books are standardized by business competition, and this will therefore be no factor in choosing a text unless some publisher engages in questionable tactics by cutting prices for a specific adoption.

This group of items relating to the mechanical structure of a book is, however, of very minor significance compared with questions of the content, style, organization, and authority of a text; and it is on the really fundamental issues that the choice of a book should be based.

SOME CURRENT TEXTS IN BIOLOGY

For High School Use

Baker, A. O., and Mills, L. W. 1933. Dynamic biology, pp. x + 722. Rand McNally & Co., Chicago.

Cole, E. C. 1933. An introduction to biology, pp. xiii + 518. John Wiley & Sons, New York.

Curtis, F. D., Caldwell, O. W., and Sherman, N. H. 1934. Biology for today, pp. xvi + 692 + xxv. Ginn & Co., Chicago.

Eikenberry, L. W., and Waldron, R. A. 1930. Educational biology, pp. viii + 549. Ginn & Co., Chicago.

Fitzpatrick, F. L., and Horton, R. E. Biology, pp. xiv + 611 + xlv. Houghton Mifflin Co., Boston.

Hunter, G. W. 1931. Problems in biology, pp. xii + 706. American Book Co., Cincinnati.

Kinsey, A. C. 1933. New introduction to biology, pp. xxiii + 840. J. B. Lippincott Co., Chicago.

Meier, W. H. D. and L. 1931. Essentials of biology, pp. vii + 529. Ginn & Co., Chicago.

Moon, T. J., and Mann, P. B. 1933. Biology for beginners, pp. x + 741 + xxxii. Henry Holt & Co., New York.

Pieper, C. J., Beauchamp, W. L., and Frank, O. D. 1932. Everyday problems in biology, pp. xxxiii + 686. Scott, Foresman & Co., Chicago.

Smallwood, W. M., Reveley, I. L., and Bailey, G. A. 1934. New biology, pp. viii + 604 + 32. Allyn & Bacon, Chicago.

Wheat, F. M., and Fitzpatrick, E. T. 1929. Advanced biology, pp. viii + 567. American Book Co., Cincinnati.

For College Use

Barrows, H. R. 1936. Elements of general biology, pp. x + 435. Farrar & Rinehart, New York.

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PART II

SPECIAL TEACHING PROBLEMS

CHAPTER XII

THE SIGNIFICANCE OF THE LABORATORY

THE LABORATORY METHOD OF instruction is science's most distinctive contribution to the art of teaching. Whether of real or of doubtful value, the laboratory has made science teaching as distinct from that in other subjects as scientific research is from philosophic theorizing or creative work in the arts. Outside of the physical sciences, the laboratory method has been copied and utilized, within recent years, as far as the materials of the other subjects will allow.

Scientists are inclined to consider the individual student laboratory as indispensable in their teaching as it is in their research. But recent investigations have been interpreted to mean that the individual laboratory is not worth the time and money spent on it. As a result teacher demonstrations are being used in place of the individual laboratory in many secondary schools and in a few of the colleges. It is therefore of moment to re-valuate the reasons for the introduction of the laboratory into the schools, and to examine the bases of the contention that there has been an over-emphasis of laboratory instruction in the elementary sciences.

FOR THE INDIVIDUAL LABORATORY

1. It is commonly urged by science teachers that individual laboratory work provides the best means of impressing students with the importance of observation as a source of information

about the physical universe. If the scientific method is a chief end of all science teaching, and if respect for observation is the chief item in the scientific method, then it seems justifiable to spend a considerable portion of the time and funds available in giving laboratory instruction. It is fairly contended that the value of the laboratory is not to be measured in the number of items remembered, but in the respect which the student develops for the method of observation.

2. Individual work in the laboratory provides an opportunity for visual, tactile, and still other sorts of observation; a teacher demonstration provides an opportunity only for visual observation. The adult too often forgets that the child asking to "see" a thing, puts out his hands to grasp it, submitting it to that tactile observation which is the chief lack in visual education—the chief difference between pictures and the real thing, between the exhibition museum and the laboratory. That seeing is better than reading is true enough, but that "doing is learning" is an age-old principle both in and out of pedagogy. Here again the value of the individual laboratory is not to be measured in specific items remembered, as much as in the weight of the impression made on the mind of the student.

3. The student acquires techniques which may facilitate his subsequent use of observation. The ability to observe accurately is one which can be improved with training. A student who has, under guidance, examined the structure of a flower, made a description of a passing bird, counted the segments in an insect's antenna, or determined the nature of anything by more careful means than is ordinarily employed is likely—so it is believed—to observe similar and even quite different things more accurately.

FOR TEACHER DEMONSTRATION

1. **The individual laboratory as usually conducted fails to teach scientific method.** Whatever the ideal, in the average laboratory "much time, space, and valuable apparatus have been expended in teaching students of natural sciences to dawdle" (Judd 1932; similarly in Downing 1934:138). It is to be feared

that there is more truth in this accusation than most science teachers are inclined to admit.

2. **In the individual laboratory too much of the student's time is occupied with special techniques,** for which he will have no use outside of the classroom in which he has learned them. The biology laboratory is criticized for the time taken in dissection, in the manipulation of the microscope, in drawing, and in setting up special apparatus in physiology. The criticism is more pertinent for chemistry and physics, and particularly for physics, with its use of elaborate apparatus. But it is quite well made against some practices in biology. No science teacher can afford to ignore this criticism, for it is directed against one of the most vulnerable points in our teaching.

3. **Teacher demonstration is about as effective as individual student laboratory.**

Since many of the data on which this conclusion is based have been obtained under the supervision of Professor Downing of the University of Chicago School of Education, his summary of the experimental work (Downing 1934: 134-145) seems a fair presentation of the viewpoint. He says that the experimental data have been accumulated by some three dozen teachers in four dozen schools, involving some four thousand students. Usually two classes have been equalized on the basis of I.Q.'s, and one is taught by the individual laboratory method, the other by the demonstration method. Tests invented by the teacher, or standardized tests, are then applied to each class at the end of each exercise, or at intervals in the course, and sometimes at the end of the course. It is stated that "An attempt has been made to keep constant all factors except the experimental one," meaning that texts, notebooks, language used by the teacher, etc., have been made as nearly identical as possible. Typical results of these studies are summarized in the table on page 104.

From such data as these, Downing concludes that "as far as the acquisition of knowledge is concerned, the demonstration method is as effective as is the laboratory method under present conditions. On the delayed test the results of laboratory instruction are superior to those following the demonstration method.

For students, either at high school or at college level, who are taking their science as a part of a general education, the demonstration method is as good under present conditions as the individual laboratory method and, considering the time and money saved, is the preferable method. Those students who are going into a scientific vocation should, at least in all but the introductory course, have enough of their work by the laboratory method to gain desirable manipulatory skills."

AVERAGE SCORES

TEACHER DEMONSTRATION VS. INDIVIDUAL LABORATORY

INVESTIGATOR	SUBJECT	IMMEDIATE TEST		DELAYED TEST		
		Demonstration	Laboratory	Period	Demonstration	Laboratory
Anibal, 1926	Chemistry	**71.11**	68.35	5 mos.	57.5	**60.85**
Cooprider, 1923	Biology	**63.86**	62.70	1 mo.	34.73	**35.09**
Cunningham, 1924	Botany	**60.3**	55.2	3 mos.	31.0	**34.60**
Johnson, 1928	Biology (A)	**51.9**	48.9	1 mo.	**42.1**	41.4
	Biology (B)	**66.19**	61.72	2-4 wks.	**60.11**	55.48
Kiebler & Woody, 1923	Physics (A)	**56.39**	53.49	2 wks.	60.3	**61.6**
	Physics (B)	64.66	**65.87**	2 wks.	56.8	**57.0**
Wiley, 1918	Chemistry	67.55	**67.92**	4 wks.	45.93	**47.60**

The better grades in each experiment are indicated in bold-face type. In the comparison of grades, note the degree of accuracy which has to be presumed in the measurement in order to find any significance in the differing results.

Naturally, the research scientist would like to know the adequacy of the controls and the significance of the measurements made in these experiments. Is it possible "to keep constant all factors except the experimental one"? Are I.Q.'s such adequate measures of the student's potentialities in observational technique (which is the prime factor involved here) that two classes can be equalized? In spite of attempts to teach with equal effectiveness in both classes, is it possible for a teacher to achieve the same efficiency in any two periods in a day? A ten o'clock class is further removed from breakfast than an eight o'clock, and there are physiological factors involved which are beyond the control of the experimenter. Moreover, at the second presenta-

tion of the subject the teacher has the previous experience to modify the repetition, sometimes for the better, often (as every teacher must know) for the worse.

Again, is it fair to average the diverse results obtained with different students, working with different laboratory problems, in such different subjects as biology, physics, and chemistry? On the dissection of a large vertebrate, for instance a hen or a cat, it is conceivable that a teacher demonstration would be more effective than individual laboratory; but it is difficult to understand how a teacher demonstration could be conducted with such a problem as the factors affecting individual variation in pulse rate of the human. In physics where the manipulation of complex apparatus is involved, might not demonstration be more justifiable than in biology where three-quarters of the laboratory (see Chapter XIII) can be conducted without a cent's worth of apparatus? It is curious that Downing sees so little significance in these varied conditions that in his eleven page summary he names the sciences which were being studied by the classes involved for only two out of the nineteen studies considered.

As for the tests by which the student achievements are measured in these studies, it is to be noted that they are measurements of facts learned under the particular experimental set-up, but no measure of the extent to which the real ends of the laboratory are attained. If it is a chief objective in all science teaching to teach scientific method (meaning, primarily, respect for observation as a source of information), we should determine how the student's respect for observation is affected by teacher demonstration, and how it is affected by individual laboratory. So far there are no such measurements available. It is doubtful whether such measurements can be made. To some of us the problem seems one of evaluation, not of measurement of physical phenomena (see p. 165).

4. **Teacher demonstrations save time.** Various investigators estimate the saving at from 15 to 50 per cent. There is undoubtedly much truth to this contention. If the number of items learned or time required to cover a standard curriculum is a chief consideration, teacher demonstrations deserve being

used. Whether the quality of the learning warrants the saving is another question.

5. **Teacher demonstrations are less expensive.** It has been estimated (Anibal 1924) that the teacher demonstration costs only 7 per cent as much as the individual laboratory. But such a generalization surely cannot apply to all specific problems. To use the previous example, individual laboratory in the dissection of a hen or cat might cost ten to twenty times as much as a teacher demonstration from a single animal, but it is difficult to see how anything would be saved by staging a teacher demonstration of individual variation in the pulse rate of the human.

6. **Teacher demonstrations require less work on the part of the teacher.** This argument is never openly made, but the alacrity with which thousands of teachers have taken the experiments cited above to constitute full justification for the abandonment of the laboratory is evidence of the wishful thinking that has been involved.

And yet, one cannot help having some sympathy with this attitude. Conducting an effective laboratory is, for most teachers, the most difficult type of work. It demands outside preparation for which the science teacher rarely gets any compensation; in many a college the laboratory teacher is required to teach two hours in order to earn as much as the classroom teacher gets in an hour. And it does take more physical energy to move about a laboratory supervising thirty students, and much less to sit in a chair at a desk while spreading out the materials for a demonstration. Again, it is simpler for an experienced teacher to do the thing himself than it is to help twenty or thirty students who are inexperienced and awkward in their technique.

All of these considerations are very real, especially for high school teachers who must teach six or seven periods each day and spend most of the afternoons and evenings at extra-curricular and community functions. But it does seem unfortunate that these are so often the real bases for the abandonment of the individual laboratory.

CONCLUSIONS

It is obvious that the above data do not warrant the exclusive use of either the individual laboratory or teacher demonstration methods. On the one hand, it seems clear that the scientist must revaluate the extent to which the laboratory is effective as a teaching device. It must be admitted that such teaching is often ineffective, and perhaps that it often fails to teach the scientific method. We have undoubtedly made a fetish of the method. In some subjects and for certain problems the laboratory may profitably be replaced with teacher demonstration or even simpler methods of visual education.

On the other hand, on the basis of the data now available, there seems to be no reason for substituting the teacher demonstration for more than a part of the individual laboratory.

The individual laboratory seems preferable:

1. For at least part of the work of all students.
2. Particularly for students planning to enter a science as a professsion.
3. In connection with problems which do not involve too much technique.
4. For solving problems which do not involve expensive apparatus.
5. Whenever and wherever the individual teacher is capable of making the individual laboratory more effective than demonstration.

The teacher demonstration method seems valuable:

1. As an occasional variation from the regular routine, designed to maintain student interest.
2. When there is an esthetic objection to the individual laboratory, as in the case of the first animal dissection, the use of some kinds of live animal material, etc.
3. When there is considerable technique involved.

4. When the materials required are expensive.

5. When the teacher, class, or equipment is not well adapted to the individual laboratory method.

The problem is not one of deciding which method is better, but of learning how to use each method effectively for the particular problems to which it is best adapted.

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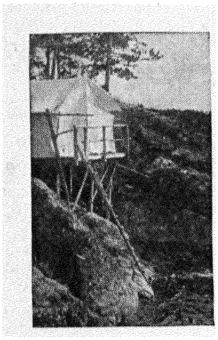
CHAPTER XIII

LABORATORY IDEALS



IF THE LABORATORY OFFERING INDIVIDUAL work to the student has not accomplished all we would have had of it, the remedy lies not in the abandonment of the method, but in an improvement of the quality of the teaching. If the teacher demonstration is to be utilized with increasing frequency, there must be some realization that there are real difficulties involved in its use; for inefficiently handled, it may become as ineffective as the poorly conducted individual laboratory.

Most of the problems discussed in the present chapter apply both to the teacher demonstration and to the laboratory for individual student use. They also apply, to less extent, to the management of fieldwork (which is a species of laboratory engaged with things that are in place, out-of-doors), though the more special problems of conducting fieldwork are considered in the next chapter.

CHOICE OF LABORATORY PROBLEMS

The choice of problems which may be effectively used in laboratory teaching involves a consideration of the following items:

1. **Centering the problem.** Each problem should present a single, clearly defined question which, it is reasonable to

expect, the class may answer on the basis of the observations which they are to make. Throughout the period the students should keep the object of the problem continually in mind. To this end, a terse statement of the question may be made at the beginning of the hour; the problem may be kept in front of the students by being displayed on the blackboard and at the head of the sheet in the notebook; the teacher may draw attention to the contribution which each item of the work is making to the solution of the central problem; and at the conclusion of the period the students may be required to answer the original question on the basis of their own laboratory observations. There should be plenty of time for class discussion of this conclusion, and subsequent examinations and student ratings should involve both the observations and the conclusions based thereon.

2. **Single problems for each period.** If more than one problem is presented in a single period the student finds it difficult to remember which material relates to which problem. The innumerable small problems included in many manuals and workbooks, many of them performable in a half or even a quarter of an hour, show a ruinous disregard of this principle. On the other hand, there is no objection to a problem which spreads over two or more complete periods.

3. **Paralleling the text assignments.** A good laboratory deals with the same subjects which are being considered at that time by the class in its textbook studies, lectures, or recitations. It is not a rare thing to find such a coordination of all ends of a course being made in the high schools; but the infrequency of such correlations in college courses in the sciences is startling, to say the least. In many colleges the lectures and the laboratory are handled by different instructors. The laboratory is often built around a morphology type course; the lectures more often give a wider survey of the biologic sciences. The laboratory should be expanded to cover all of the sciences which are presented in the lectures, or abandoned when the lectures deal with subjects that are not really adapted to laboratory presentation. There is a long-standing tradition that there

must be a regular alternation of laboratory and lecture or recitation periods each week throughout the semester; but it would make for more effective teaching if the laboratory occurred with greater frequency in those parts of the course to which it can best contribute, and if the number of laboratory periods were reduced or the laboratory even abandoned in connection with units in which some other method of instruction would prove more effective.

4. **Illustrating all aspects of biology.** As a matter of fact, the common restriction of the laboratory to material in morphology and physiology is quite unnecessary. The other biological sciences (taxonomy, distributional biology, genetics, and behavior) are quite as conveniently and quite as effectively illustrated in laboratory problems. Chapters XVII to XXIII in the present volume show what possibilities there are in these ordinarily unused fields.

It is, however, difficult to persuade a teacher to conduct a laboratory on a problem which was not worked out in his own college courses. There are, in the available workbooks, problems which have been successfully used by thousands of teachers, while other thousands who have seen the same problems have never tried to use them—for no other reason than that they have never worked them before.

5. **Dependence on student observation.** If the solution of the problem does not demand independent observation on the part of the student (even when the teacher is making the demonstration), the laboratory fails in its chief objective, the teaching of the scientific method. In the last twenty years, nothing more grotesque has befallen the teaching of the sciences than the parading of educational inventions as laboratory work designed for beginners in the sciences. Many of the latest workbooks are filled with true-false tests, completion tests, matching tests, and range of information tests. Students are asked to use data accumulated by others to build lists, tables, and charts. They are asked to make diagrams showing the death rates in states with or without vaccination laws, to make lists of birds that eat insects, seeds, mammals, etc., to diagram the path by

which a piece of bread travels from the mouth to the ultimate tissues in the muscles, to make detailed drawings of human structures which they know only from the textbook diagrams. Many of these exercises are splendid means for testing the student's comprehension of textual material, but as laboratory problems they entirely miss the point. They do not force the student to use his eyes and other sense organs in the first-hand observation of natural phenomena.

Reference readings on which reports are made, much as they may contribute to the course as a whole, are similarly unacceptable as laboratory work. Even observations made by way of photographs, lantern slides, and models, and the accumulation of such materials into scrapbooks are not the equal of observations made on real plant and animal materials.

6. **Technique vs. observation.** A good laboratory involves a minimum of technique and a maximum of opportunity for observation. As already noted, science teaching is commonly and quite justly criticized because students find the mastering of technique the main objective, and the gathering of observed data the incidental outcome of the laboratory. Specifically, the techniques most often over-emphasized in biology are those of microscope manipulation and, conspicuously, the making of drawings; less often over-emphasized is the use of other apparatus.

The compound microscope is the most expensive item of the biology laboratory equipment. It might very well be eliminated from the secondary schools, except for the occasional use of a demonstration instrument. Although it has been the indispensable tool of the research biologist, it is unnecessary for an understanding of that part of the world with which the average future citizen makes contact. The few microscopic structures (like cells, chromosomes, bacteria, etc.), which should at some time be seen by all educated persons, may be demonstrated from an instrument or two set up and focused by the teacher, or from an instrument attached to a projection lantern (see Appendix: Laboratory Equipment).

The technique of dissection is so difficult for beginning students

that it should be limited to simple problems. The dissection of more delicate structures may be left to advanced classes.

In units on physiology, too much of the apparatus of the chemistry and physics laboratory is ordinarily introduced. Analyses of foods and other materials concerned in metabolism usually involve too much technique to warrant their use as problems in the elementary biology course.

Drawing is the traditional accompaniment of laboratory dissection, but its use has been subjected to severe criticism. It is quite true that the making of a drawing provides a means for directing one's observations. It may even be true that an accurate drawing cannot be made unless the observations are accurate. But it certainly is not true that inaccuracy in a drawing is evidence of inaccurate observations. Accuracy here depends in no small degree upon a mastery of the technique of drawing. For the majority of us, skill in handling a pencil comes only as a matter of long practice, and drawing is, therefore, not a good means of testing the quality of a beginner's observations. Among secondary school teachers there is a growing inclination to avoid drawings by asking for tabulated records, oral reports, and student demonstrations at the conclusion of each laboratory period. These methods seem to work satisfactorily. Drawing is to some extent retained as a quicker means of recording certain data, but prepared workbooks minimize the technique by providing simple or incomplete outlines into which the student draws the details.

The colleges have been slower than the secondary schools to effect any reform in their over-emphasis on drawing in the laboratory.

7. **Student exploration.** A good laboratory encourages independent exploration on the part of the student. With a very few suggestions, students are often able to devise their own techniques for finding the answers to the questions implied in the problems set for them. If the students can be interested to do this, they will find the exploration of laboratory materials not altogether unlike the exploration of new oceans and continents. Though many teachers prefer to use some sort of lab-

oratory guide, printed outlines, manuals, and workbooks too often interest the students in the completion of assigned tasks, rather than in the solution of their own problems. Where manuals or workbooks are used, the students should be encouraged to seek the answers to such side-issues as the main problem may suggest.

8. **Bases of conclusions.** Conclusions should be based on the particular observations which have been made. The conclusion should provide the answer to the question implied in the formulation of the problem. It should be a generalized statement of the data actually observed. The limited observations made by the class cannot constitute a complete validation of the biologic principles which are found in the text, for textbook statements are based on many observations, and sometimes on many thousands of observations.

9. **Keeping students occupied.** A good laboratory keeps each student occupied all of the time. If they are not so occupied the laboratory becomes listless, disorderly, or even riotous. Teachers who have no difficulty with discipline at other times, come to dread the difficulties of maintaining discipline in a laboratory. If enough real work is provided for each student, the disciplinary problems will be largely solved.

With students of diverse interests and capacities, uniform assignments bring some members of the class to the completion of a problem long before others have finished, and the first students must not be left idle while the others are completing their work. But for the slower ones, the point of the laboratory is lost if time is not allowed to carry the work to completion. Some teachers make allowances for these individual differences by assigning different problems to each student, but this reduces the opportunity for class discussion, and so complicates the management of equipment that the method is not very practicable. It would seem reasonable to dismiss each student as soon as he has completed his work, but as a matter of school discipline this is not usually possible in the high school; and even in the colleges, where such a procedure may be possible, it prevents group discussion at the end of a period. The best way of uti-

lizing individual differences in student ability seems to lie in the choice of laboratory problems which provide for an extension of work for some and a minimum of work for others. If the dissection of one grasshopper is the minimum allowable, the faster workers may be inspired to dissect a second specimen of the opposite sex, to travel about the class taking note of individual variation in the specimens dissected, or to take time to study such a difficult structure as the insect's brain. Or, again, if at least a hundred lima beans are to be measured for a study in variation, the faster students may be instructed to measure as many more as the time allows. It is a poor laboratory problem which cannot be adapted in this fashion.

LABORATORY ADMINISTRATION

While each teacher will have to work out the laboratory procedure to which he is best adapted, the following items are drawn from the experience of numerous good teachers.

Assigning laboratory materials. In the high school, there is no equipment needed for permanent assignment to individual students; and this may be true of the introductory course in the college, although here microscopes, dissecting pans, etc., with lockers and keys, are often assigned to individual students. All equipment and supplies may be stored in accessible cupboards or on shelves, from which the students may draw the equipment necessary for each day. Or materials may be spread out on a table from which the class, passing in cafeteria style, may take the items called for in the workbook or noted on the blackboard.

Previous planning. Without previous planning, no laboratory can be successfully run, no matter how many times the teacher has gone through the same exercise. The total list of equipment should be provided, or its subsequent provision planned for, some time before the semester begins. Once a week the laboratory materials necessary for the following ten days should be checked, and earlier consideration may be necessary where live animal or growing plant material is to be prepared.

Preparation of materials. Such preparation must be con-

fined to the minimum, especially for busy high school teachers. It is common practice to divide the class into squads of three or four, and to ask each squad in turn to prepare the materials for the whole class during a period of a few days or a week. This saves time for the teacher, and also proves a source of interest and instruction to the students.

Notebooks and workbooks. There is something to be said for having the students make their own notebooks; but a well-organized workbook may provide blank tables, outline guides for drawings, etc., thus saving the student considerable time. Either the individual sheets or the whole workbook should be handed in each day or once a week. Its prompt correction and grading by the teacher is essential if the student is to profit therefrom. There is much to be gained by having the teacher pass about the laboratory near the end of each period, grading each student before he leaves the room.

Double periods. Teacher demonstrations ordinarily do not need so much time; but there is almost no laboratory work which can be profitably performed by the individual students in less than an hour. Even with beginning students in the high school a double period (80 minutes or more) is needed for the most effective teaching.

The full hour period which is now popular in the high schools usually fails in all subjects to provide the intended opportunity for half an hour of recitation and half an hour of supervised study. The full hour period has also ruined laboratory teaching in the sciences by eliminating all possibility of a double period. Those who worry over the relative efficiency of the individual laboratory and teacher demonstration, might well give some attention to this latest contribution to the inefficiency of science teaching in the high schools.

Teacher's pay for laboratory instruction. Effective teaching in an elementary laboratory demands fully as much and often more work than recitations or lectures covering the same number of clock hours. In some high schools the science instructor is, however, asked each day to teach an hour or two longer than the teachers of textbook subjects, and there are many col-

leges and universities which compute the normal teaching load by reckoning two hours of laboratory the equivalent of one hour of recitation or lecture. It is obvious that the administrators responsible for this are not teaching and have not taught in the laboratory. As a direct result of this unfair practice, there are science teachers in both the secondary schools and colleges who decide that their subjects can be taught without a laboratory, college science departments in which the older men avoid laboratory teaching but require the younger men to conduct such courses, and everywhere teachers who consider that half of their attention is all that they owe to the laboratory for which they receive half pay.

Constant attention of the teacher. The elementary laboratory needs the constant attention of a teacher. Although it was Agassiz' custom to provide the materials and then to leave his classes without instructions or supervision, the testimony of his students is not unanimously in favor of this sink-or-swim method. Even where students are inspired to invent some of their own methods of investigation, the teacher must help a beginner secure the materials, facilitate his technique, ask the stimulating questions which will lead him in his thinking, and make sure that he draws warranted conclusions from his work. If the teacher performs the dissection or experiment along with the class it is surprising how many items of technique and biologic questions may be recalled, even by the most experienced teacher. This method also gives the students an opportunity to explore with the teacher.

Order and cleanliness in the laboratory. Advice on this point would seem too trite to be given space, except for the fact that there are some biology teachers who tolerate disorder and dirt in the laboratory. The unfavorable reactions thus aroused in beginning students may do more damage than the best teaching can offset. For nearly thirty years I have been haunted by the memory of the abandoned torso of a cat and the dissecting pan of filthy water which stood for a week in a certain high school laboratory that I knew. It is difficult to understand why the refuse from college laboratories should be

cleaned up with less care than is given the refuse from our kitchens. Odors of preserving fluids (especially formalin), sinks clogged with dissecting pan wastes, chewed-up remains of animals or dried-up corpses of plants, inadequate supplies never conveniently accessible, a poorly planned routine, and the tolerance of disorderly conduct in the laboratory will do anything but convince the student that it is an interesting world in which we live. Moreover, it is to be doubted whether such disorder in material contributes to that orderly manner of thinking which should be characteristic of the scientific method.

Size of laboratory class. The average teacher probably does his most effective teaching in a laboratory with not more than twenty or thirty students. But we have probably gone to an extreme in recommending small classes, and it is certain that some teachers are capable of handling more than thirty with considerable efficiency—reckoning the cost per unit of instruction and the quality of the return to the state. Efficiency varies considerably with different teachers, with diverse equipment, with the personnel of the class, and particularly with the nature of the problems employed. With larger classes it may be necessary to omit some of the problems which would prove quite effective with smaller classes.

LABORATORY EQUIPMENT

Cost. The cost of equipment in the biology laboratory probably averages less than half of that in physics or chemistry. This is one of the reasons for choosing biology as the introductory science in the secondary schools. The average cost of the permanent equipment in biology in the high schools is between $150 and $1,000, and the annual expenditure for materials something between $50 and $200. These figures may be recommended as standards within reach of the average small school. There are high school laboratories with equipment valued at several thousands of dollars (chiefly spent on microscopes, models, and museum preparations); but one often finds, as David Starr Jordan once remarked, that the output

is in inverse ratio to the amount of equipment. Therefore one is inclined to present plants and animals in the laboratory without too many pieces of apparatus intervening between him and the students.

Problems requiring no equipment. There is a long list of laboratory and field problems which may be worked with no equipment beyond such things as pencils and paper, chalk, timepieces, etc., common to all school rooms, and such plant and animal materials as the students can readily obtain. The following is such a list of problems, taken from the author's *Workbook in Biology.*

60 Double Periods of Laboratory

Without Special Equipment

General	Page References in Kinsey Workbook
Out-of-Doors	1
Living Things	3
Spring Flowers	277
The Seven Biologic Sciences	279
Taxonomy	
Plant Groups	5
Review of Plant Classification	9
A Census of Conspicuous Plants	11
Animal Groups	13
Review of Animal Classification	15
A Census of Conspicuous Animals	17
Tree Species, Genera, and Families	19
Another Form of Key	31
A Discovery Game	33
Distributional Biology	
Life Zones	47
Life Zones and Regions	55
Morphology	
Grasshopper: External Structure	59
Earthworm: External Structure	69

The most essential equipment. Lists of the most essential equipment will vary widely, depending upon the particular problems that the particular teacher plans to work. The following is, therefore, only a sample of such lists. It is based on a choice of problems in the author's *Workbook in Biology*. For a class of 20 students, the estimated cost of the permanent equipment would be about $120 (to be spread over several years), and the cost of the annual supplies about $15.

Most Essential Equipment

10 Schmitt boxes for insects
20 Cardboard insect boxes
Mounted insect collections
2,000 Insect pins
10 Insect nets
20 Insect killing bottles (bought or made)
3 Digging forks (10-inch)
24 Forceps
10 Atlases *or* pocket maps
20 U. S. relief maps (from Superintendent of Documents, Washington, D. C.)
10 Sets of colored crayons
20 Ears of hybrid corn (from G. S. Carter, Clinton, Conn.)
25 Stuffed birds (or Audubon bird pictures)

6 lbs. Dried lima beans
20 Millimeter rules
3 Tape measures
20 Test tubes
5 Test-tube holders
1 Alcohol lamp (or Bunsen burner)
2 pkgs. Filter paper
2 Medicine droppers
5 Glass funnels
20 Fruit jars: quarts
20 Fruit jars: pints
100 Small glass vials
8 doz. Paper bags, 2 sizes
150 Long wire nails
Cord or twine, sealing wax, elastic bands, wire paper clips, pins, library cards, corks, candles, iron filings, absorbent cotton, bandage, etc.
Glue or Duco cement
70% alcohol
2% formalin
Nitric acid, ammonia, hydrochloric acid, potassium cyanide, iodin, coconut oil, sodium hydroxide, Fehling's (or Fehling-Benedict) solution, fibrin, pepsin, pancreatin, etc. (to be found in the school chemistry laboratory or local drug store)
Live grasshoppers, earthworms, tadpoles, frogs, etc.
Moss plants, fern leaves (fresh or dry)
Carrots, squash, cabbage, seedlings of corn, beans, and other live plant material
Vinegar, salt, sugar, nut shells, milk, pork, etc. (in small quantities, usually obtainable without expense)
Reference books (buying about 4 per year)

Annual supplies. Preserving fluids, breakable glassware, chemicals, drugs, dissecting materials, growing plants for experiments, etc., need yearly replacement. Many high school teachers engage in the very bad practice of buying such annual supplies out of their own pockets. The resulting tendency to skimp lowers the teaching efficiency. It is a legitimate function of

the teacher to persuade the school administration that the annual expenditure of about one dollar per student is warranted by the return on the investment. On the other hand, too many teachers depend on supply houses for materials which could be obtained by the students themselves; and much interest may be aroused and first-hand information acquired when students have to collect the grasshoppers, earthworms, flowers, and stems which they are to dissect, the leaves they need for studies in individual variation, the ants for their behavior experiments, etc. Students may be asked to collect such material, individually, out of school hours; or the whole class may take part of a laboratory period to gather what is needed for a series of problems.

Furniture and arrangement of laboratory. That there is some misunderstanding of the function of the laboratory is evidenced both by the number of schools which use the arms of desk seats as their "laboratory tables," and by the considerable expenditure to which other schools may go in providing elaborate furniture. There is much to be said for the use of a laboratory as a classroom; but a classroom (even if equipped with desk-armed chairs) makes a very poor laboratory. The essential minimum of a laboratory is an equipment of seats, enough table space to allow for the convenient spread of the materials, and light adequate for good observation. There are manufacturers of special furniture and elaborate lighting systems (see Appendix), and such equipment is probably the best long-time investment for school systems that can afford it; but no teacher need feel that the efficiency of the laboratory is very much reduced if he can have no more than the cheapest wood tables (kept well varnished or painted to avoid damage), the cheapest stools, and the most inexpensive crook-necked desk lamps on the market. Daylight is better than lamp light, especially if it is daylight from a northern window. If the laboratory windows open onto the out-of-doors the students may be continually reminded that biology is the science of life. Wall shelving or closed cupboards, a blackboard, metal waste baskets, a tightly closed (and frequently emptied) garbage can for objectional

wastes, and a white enamel sink with enameled drain-board ($30 at the local plumbers') are the chief needs in furniture.

The supervision of the laboratory is much simplified if it is no larger than necessary to give working room to the maximum class (20 or 30 students) which will be admitted. Many college teachers consider that larger classes are handled with greater efficiency if they are spread into a series of small rooms, each with its individual instructor, but with a supervisor coordinating the work of all of the laboratories.

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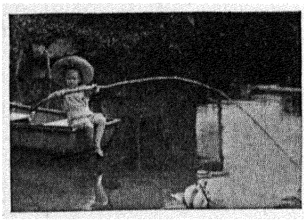
CHAPTER XIV

THE PROJECT METHOD IN BIOLOGY



As ORIGINALLY UNDERSTOOD IN science teaching, the project is a type of laboratory problem carried out by the student with a maximum independence of the teacher's help. It is the laboratory method in its most individualistic form. As such it may have all of the values of independent laboratory work, and all of the faults of poorly directed experimentation. The more original and independent the investigation the more likely it is to arouse the student's interest, curiosity, and initiative; but the more likely it is to become a matter of conquering technique. The limitations of the project method are greater than the present popularity of the term would indicate, but its merits are still enough to account for its enthusiastic use by many good teachers.

After all, the project method is the very essence of scientific research. It was the only method of instruction used before there was classroom teaching in the natural sciences.

With the extension of the method to fields outside of the natural sciences, the title of *project* has been expanded to include everything from reference readings to the accumulation of new information through original observation. But in science teaching, there is something to be gained in restricting the term, as it was originally applied, to observations independently pursued, largely outside of the scheduled classroom and laboratory hours, and with a minimum of teacher supervision.

CHARACTERISTICS OF GOOD PROJECTS

A good project:

1. **Offers the maximum opportunity for direct observation.** The building of apparatus or the accumulation of materials in scrap-books, for instance, is not the biology project in its best form. As with the biology laboratory problem, the undertaking should be chiefly concerned with observations made by the student. Thus shaped, the project becomes a superb means of teaching the scientific method.

2. **Has a solution which is within reach of the student.** It should be possible for him to obtain "results" without the expenditure of too much preliminary work on matters of mere technique. Otherwise his interest will not be maintained. The need for microscopic examinations and the necessity of learning how to use complicated apparatus may seriously reduce the opportunity to make observations. If the plants or animals involved in the project are difficult to find, to collect, or to preserve, the student may not be able to obtain significant results in the available time.

3. **Leads to conclusions which are warranted on the basis of the student's own observations.** While he may want to know what others have done, and may be expected to look at some of the published information on the subject of his experiment, he should have a clear conception of the significance of his own observations as apart from the data derived from other sources. This will provide training in the scientific method.

The simplest conclusions are usually generalizations which cover and include all of the specific observations which have been made. Observations on the color variations of a certain variety of flower may culminate in the generalization that "the color was observed to vary from white through pink to red-purple." A series of observations on locations of nests of robins may be summarized in the statement that "the nests have been observed in many different types of places," a list of which is

then added. Discourage the tendency to draw grand principles from the few data which have been obtained. In the cases given above, avoid generalizations about the nesting habits of robins in general, or explanations as to *why* the flower color is so variable.

While experiments are more interesting than simple observations, there are grave difficulties involved in drawing sound conclusions from them.

4. **May be pursued independently by the student outside of class hours.** The accumulated collections or experimental apparatus used in a project may well be kept in the school laboratory where the entire class may become interested in the investigations in progress. But there is something to be gained in having boys and girls carry the scientific method onto the streets, to their homes, and to all of the world through which they move.

5. **Does not demand too much attention from the teacher.** It is a serious burden on the teacher's time and attention to direct twenty to a hundred or more independent projects, especially if very much of this direction must be given outside of scheduled classroom hours. Some teachers are surprisingly efficient in conducting fifty-ring circuses, but for most of us, project teaching is a very time-consuming performance. This is the prime reason that this method does not replace all others in science teaching.

6. **Requires a reasonable time for its working.** To the beginner, too short a project may appear trivial, and too long a project may cease to be interesting before it is completed. If each student is asked to work several projects he is likely to become confused as to the significance of each. A project extending over several weeks or even for a couple of months seems to work well with high school students.

7. **Is selected by the student.** It becomes a matter of individual pride to each student to complete a project he himself has selected. If the student does not readily find a problem in the list submitted to the class, the teacher may, by adroit sug-

gestions, arouse the student's interest to the point where he will find a subject to his liking.

8. **Allows the student to develop his own methods** for the solution of the problem. His interest in the problem will become much magnified if he finds he can work out his own means of salvation; but if his interest is to be maintained the teacher must stand ready to offer advice before too much time has been wasted in false moves or unprofitable experiments with difficult techniques.

It is even well to allow the students to manufacture much of their own equipment out of such everyday materials as tin cans, empty bottles, kitchen utensils, etc. Such tools have a peculiar way of making observations seem more important than the means by which they are obtained. One of the most instructive laboratory and project guides in biology (Osterhout 1905) was written by a research physiologist who delighted in using such ready-to-hand apparatus in his elementary teaching—often manufacturing the equipment after the class had arrived in the laboratory.

9. **Has the frequent advice of the teacher.** A minute of the teacher's time, now and again, or ten minutes scheduled for a weekly conference will suffice for finding out what specific results are being obtained by the student, and encourage him to do steady work on his project. Although the teacher must be available at still other times to examine accumulated data and to offer opportune advice, reports cannot be accepted at any and every hour of every day without becoming an undue burden in the teaching program.

The whole class may profit by hearing an occasional progress report, but most of the reports should be made personally to the teacher. An endless succession of reports made to the class may become very tiresome, consuming more hours than their value may warrant. Condensed summaries of some of the best of the final reports may be made by the students or (better?) by the teacher to the whole class.

10. **Involves the element of contest.** It may be understood that the best two or three projects worked in the semester

are to be presented as special reports to the whole class. Tangible rewards (such as biologic books, insect or plant collecting equipment, etc.) may be offered for superior results. The class may be divided into halves or smaller groups ("teams") to work on single projects, and interest in the success of the team may encourage the student to do better than he would if working alone. It is sometimes desirable to develop a system of points to be awarded for each project that is completed; but experience with such set-ups in boy and girl scout and campcraft activities indicates that point systems may invite the student to do superficial work. Quality must always be considered more important than quantity if systems of awards are not to become pernicious.

11. **Occupies not more than a small part of a year's course.** A constant string of projects, with no sign of their surcease until the end of the year, may become a bugbear to young students. Like the "contracts" with which it is fashionable to load students in some other courses, projects may also become an exasperation to parents who are expected to substitute for the teacher in their supervision. In most cases two or three good projects are enough for a year. Only the especially qualified teacher should do what a few high schools have done in abandoning all other forms of instruction and building an entire program out of projects.

SUGGESTED PROJECTS

There is probably no other subject in the curriculum which offers as many possibilities as biology offers for projects with beginning students. The following short list is merely suggestive of the activities which any inventive teacher can adapt to local conditions and extend indefinitely.

Collection projects. The number of species asked for in each project must be large enough to require more than casual observation. The lists must be adjusted to each school, class, and season. In addition to the collections demanded by these

projects, the student should be asked to learn the names and identifying characteristics of his material, and perhaps to make some record of the biology observed with each specimen collected.

(25) Weeds
(20) Spring flowers
(30) Composites
—— Flowering plants
—— Plants of one family
Photographs of mammals
Photographs of birds
Leaves of trees
Bark of trees
Photographs, whole trees
Wood sections
Cultivated shrubs
Ferns and allies
Mosses
Woody fungi
Devices effecting seed dispersal in plants
Fossils
Abnormal types of leaves on a tree
Plant diseases
Bird nests (after they are abandoned)
Insects (of all kinds)
Collection of harmful insects
Collection of beneficial insects
Families of beetles
Families of moths
Species of butterflies
Plant galls
Household insect pests
Shells
Instances of protective coloration in animals
Parasites
Plant fruits

Life history studies. These should emphasize the significance of prolonged observation, asking for long-time records of single individuals and of numerous individuals of a single species.

Pantry or carpet beetles
Moths and butterflies, reared from larvæ to adults
Case (caddice) flies
Guinea pig, rabbit, dog, or some other pet
Toads or frogs, from eggs to adults
Nesting of a bird
Feeding activities, one species of bird, over a long period
Life history of a bean plant
Life history of a pea plant
Life history of a radish plant
Life history of a fern
Other plant life histories
Plant and care for a flower or vegetable garden
Plant and care for a wild flower garden
A honeybee colony
An ant colony (in a glass nest)

Pure observation projects. These involve little more than direct observation of materials gathered. They are most likely to arouse interest when they involve observations of live and normally active plants and animals.

Behavior of ants
Behavior of social wasps
Behavior of solitary wasps
Behavior of solitary bees
Behavior of social bees
Behavior of caterpillars
Behavior of dung beetles
Behavior of spiders
Frog and toad mating behavior
Number of seeds produced in typical plants
of several species

Surveys. These become true projects when they call for reports, maps, charts, or lists which are built entirely out of observed data.

Map the shade trees in a given area
List and map all organisms in a 30 foot square
Bird migration record
Hereditary characters in one's own family
Mosquito breeding places
Fly breeding places
Sanitary survey of several town blocks or several farms

Experimental control. These are projects in which the course of normal processes is directed, stopped, or otherwise modified. The student is asked to observe the results of the experiments, and to make careful analyses of the factors involved.

Make various types of grafts
Devise means and clear a lawn of all weeds
Grow plants under various conditions of moisture
Grow plants under various conditions of light
Grow plants under various conditions of soil
Grow plants under various conditions of temperature
Establish the balance in an aquarium
Build and put up several bird houses, recording the nestings that are made in them
Feed birds over a winter period
Build and care for an experimental ant nest
Experiment with mound-building ants
Plant and care for a hotbed
Work regeneration experiments with worms, tadpoles, etc.
Make a hay infusion (as an unbalanced aquarium)
Control grasshoppers in a field or garden
Control insect pests on some garden plant

Conducting exhibitions. These are of doubtful value as projects, demanding more organization than observation. They can become good projects if the students are asked to select the

prize products exhibited and to prepare a report on some phase of the biologic data available in the show.

Hold a flower show in the school laboratory
Hold a vegetable show
Hold a fruit show
Hold a pet show
Exhibit collections which have been made
Exhibit material to illustrate a principle of biology

While many of the projects listed above present material in taxonomy, morphology, physiology, or some other specific science, many of them combine several approaches and need not be correlated with any particular unit in the year's course.

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CHAPTER XV

FIELDWORK IN THE BIOLOGY COURSE

THAT FIELDWORK IS SO RARELY given an adequate place in biology teaching is due to a misapprehension of the difficulties involved in its management. For most teachers would be ready to agree that such work, well conducted, may contribute materially to the accomplishment of our first end in the course: To interest students in the world in which they live.

In the field one may find illustrations of the principles formulated in the textbook, translate laboratory material into living organisms, and see biologic phenomena as the whole which they can never be in the classroom. This is fundamental for the student who is the average citizen; it is even more indispensable for the biologist in training. Unfortunately, in recent decades there has arisen a generation of teachers and investigators whose conclusions are characterized, as never before in the history of biologic research, by their inapplicability to anything but the limited material which chances into their laboratories. It is due to our own negligence as teachers that we find it increasingly difficult to obtain graduate students, and men to add to our college staffs, who have anything of the out-of-door background which a student of plants and animals should have. Teachers of elementary classes both in the secondary schools and in the colleges may serve both the average future citizen and the future biologist by mastering the difficulties and putting fieldwork into all of their teaching.

The unique problems of teaching in the field may be met with the following recommendations.

UTILIZE COMMON MATERIAL

Most teachers conceive of fieldwork in terms of wide expanses to which the class may make an all-day journey once or twice a year. But if such work is to become as regular a part of teaching as it should be, it must be managed in the area that can be reached in the double period ordinarily allotted to the laboratory. This is possible only if one employs the materials to be found along city or suburban streets, in markets and other food-handling establishments, in vacant lots, and in cultivated plantings. It is a matter of much interest to run field trips in the city. Methods classes working in smaller communities should, on occasion, be transported to a larger city so they may become aware of the abundance of interesting biological phenomena to be found even there. In a survey of some twenty schools in Chicago, only three were found to be so located that a dozen or more trips could not have been run within two blocks of the building.

One may spend an hour examining the dandelion that even the city back street will furnish: its name and folk-lore, the flower structure, its adaptation to pollination and its ability to produce seeds parthenogenetically, the sleep movements of the flowers and leaves, the mechanics of the upright stem (mentioning dandelion curls and more technical experiments), and the efficacy of the hollow stem as a supporting structure, the advantage of the tap-root, the marvel of the seed structure ("she loves me, she loves me not!"), the place of the thing in the struggle for existence, and its significance as an immigrant replacing native plants. Similarly there are clovers and plantains and sheep sorrel, and others of the most despised plants of the vacant lot which may furnish as good material for a trip.

A single tree may illustrate enough ecology for another period. Rare is the school which does not have at least one tree within a ten minute walk. The more horse-bitten and smoke-choked and

light-starved the tree may be, the better it is as material for a study of ecology.

The cultivated shrubs and trees, and such lesser plants as even small doorways may boast, may furnish as good material for an elementary study of taxonomy as an equal number of native species found in the wild. But there are so few college courses in botany which mention the horticultural plants that most teachers have acquired a habit of overlooking cultivated material as a source of biologic phenomena.

It is surprising how few classes see the opportunity to study biology in fruit and vegetable markets, grocery stores, meat shops, lunch rooms, drug stores, clothing shops, furniture stores, lumber yards, flour mills, slaughter houses, greenhouses and florists shops, private gardens, hospitals, city water plants, sewage disposal plants, poultry houses, dairies, etc., some of which are available in almost any community. It is, of course, necessary to make previous arrangements with the owners, and care must be taken that the class does not interfere with the normal activities of such places, but these are no real barriers to the use of the man-made sources of biologic material.

It would take an entire volume to present detailed outlines for all the trips possible for city schools, and a longer list is, of course, available for rural schools. But the possibilities may be suggested by tabulating the trips which one class of prospective biology teachers found it possible to run within two blocks of the high school in a typical city of 20,000 inhabitants.

58 Field Trips

Possible Within Two Blocks of a Small City School

The page references are to the detailed outlines in the author's Workbook in Biology.

Taxonomy
- Plant Groups (p. 5)
- Animal Groups (p. 13)
- Tree Species, Genera, and Families (p. 19)

Insect Species, Families, and Orders (p. 21)
Insect Collecting Trip (p. 23)
A Discovery Game (p. 33)
Taxonomic Characters of a Single Species of Plant
Tree Identification by Leaf
Tree Identification by Bark and Buds
Tree Identification by General Form
Landscape Values of Trees
Landscape Uses of Shrubs
A Shade Tree Map
Bird Identification

Morphology

Leaf Structure (p. 87)
Stem Structure (p. 95)
Root Structure (p. 101)
Structure of a Typical Flower (p. 105)
Flower Record (p. 109)
Plant Structures Used as Foods (p. 115)
Autumn Colors
Dandelion Structure
External Structure of a Grasshopper (p. 59)

Physiology

Some Physiologic Processes (p. 129)
Classification of Market Foods (p. 141)
Commercial Producers of Foods (p. 145)
Fly Breeding Places (p. 161)
Mosquito Breeding Places (p. 163)
Restaurant Biology
Community Sanitation
Hospital Biology
Trip to Creamery

Genetics

Good Breeds and Bad Breeds (p. 169)
Individual Variation (p. 173)
New Breeds (p. 175)
Some Plant Adaptations (p. 181)
Limestone Fossils

Ecology
- Ecologic Relations (p. 185)
- A Field Survey (p. 187)
- Mid-Winter Plants and Animals (p. 189)
- Habitats (p. 193)
- Forest Products (p. 203)
- Composition of Soils (p. 195)
- Weeds and Epidemics
- Enemies of Cultivated Plants
- Census of a 10-Yard Square
- Cross-Pollination

Behavior
- Plant Sleep Movements (p. 225)
- Leaf Mosaics (p. 235)
- Instincts in Domesticated Animals (p. 241)
- Experiments with Ants (p. 243)
- Ant Nests (p. 245)
- Bird Behavior (p. 255)
- Bird Nests (p. 261)
- Bird Migration Record (p. 265)
- Spider Behavior

General
- Out-of-doors (p. 1)
- An Observation Race (p. 275)
- Spring Flowers (p. 277)
- Principles of Landscape

It is obvious that a single small area in a city may provide more fieldwork than is needed in a full year's program. The chief difficulty comes in avoiding monotony in the routing of such trips, and thus it becomes desirable to use cars or buses to travel to more remote places on an occasional Saturday or holiday.

LIMIT THE SUBJECT OF EACH TRIP

If field trips are free-for-all observation tours, it is true, as often objected, that the material will be too disorderly to have

very much teaching value. Each trip should be limited to a single subject representing the unit being considered by the class in the textbook and laboratory work of the same period. The lists given above offer suggestions for such limitations of the subjects.

The restriction to a single topic should not, however, prevent observation of other rare and striking phenomena which may come within the range of vision. There are pedagogical values in turning aside from a trip on spring flowers to watch a buzzard go up into the blue; and the unusual activities of a dung beetle or ant colony must not be missed because the chief subject of the trip is fly breeding places. Such side issues contribute something to the maintainance of student interest, and much to the conception of the living world as a whole; but the art of teaching in the field involves a use of such diversions without detriment to the central theme of the hour.

TO MAINTAIN DISCIPLINE, KEEP THE CLASS AT WORK

A great many teachers who have no difficulty with discipline in the classroom or laboratory, find it difficult in the field to keep the interest of a class centered on the program at hand. It is on this account that school administrators and parents, particularly in small towns, may object to fieldwork.

To keep a field class profitably at work it is necessary that each student be continually engaged in individual observation. Too many field trips degenerate into a series of short lectures, each given by the teacher as he confronts the plant or animal involved. To ask the students to stand in a classroom while listening to a recitation or lecture would be a certain cause for disorder; and the method works no better in the field. The teacher's function in the field is not that of a demonstrator, but that of an instigator of independent exploration by the students. Instead of pointing out that there are five leaves in a cluster on the white pine but only two on the red, the teacher should ask that each student determine how many leaves are in the clusters on the two trees, calling for such a survey as may

show whatever individual variation there is in the leaves, and directing the comparison of the differing results that may be obtained by the several students. The teacher who leads a class through a garden or greenhouse with the remark that there are fifty kinds of narcissi there, differing in proportions of perianth and cup, size and color of flower, flower arrangement on stem, season of bloom, etc., will find the class more interested in unscheduled diversions. The teacher who asks the students to determine the number of varieties in such a garden, and to list the characters in which they differ, has solved the disciplinary problem for some time to come and, incidentally, has done something to impress the class with a scientist's evaluation of observation as a source of information.

Often it may be necessary to provide extra activity for the student who has more physical energy than others in the class. For instance, the superabundant activity of one boy in one class was directed into tree-climbing, as a result of which the class handled much unique material which was ordinarily out-of-reach, and the boy's interest in biology was considerably increased.

Any field class should be given enough physical exercise to make it appreciate an occasional pause to look at biologic material. This is the method employed by leaders of boys' and girls' clubs in which the meetings are started with calisthenics, a vigorous game, or other physical activity. The equivalent on the biology trip is to start with a hike which is long enough to weld the class together as a slightly tired whole. In using material from the school-yard, it may be necessary to begin with a journey around the block. I have run up many a hill with biology classes which saw only the human aspect of the competition, ignorant of my plans to center their attention on the plant material ahead. No class in the field should be held at any one point longer than their interests will keep them there; at the very first sign of straying attention or disorderly conduct the trip must move on.

The size of the field class must be so restricted that the instructor is able to keep the group occupied with the subject

under consideration. Twenty or thirty students can be kept busy on most subjects—a tree study, for instance. It is more difficult to manage a half dozen in problems on insect behavior. It is possible to handle companies of a hundred or more boys and girls, but such large groups can be managed only if the subject selected for the expedition provides for the independent activity of everyone on the trip.

Disciplinary difficulties commonly arise because the students feel they are not expected to understand or remember very much of what they see in the field. In summary discussions at the end of each trip, in subsequent class discussions, in written examinations, and in the final grading the class should be held for the fieldwork just as they are held for the textbook or laboratory data. Unless the teacher attaches such importance to the field observations, the class cannot be expected to give its attention to them. Each student should be expected to make notes, in the field, of all significant observations, carrying a small notebook or a workbook and pencil for such purposes. At the end of each trip, or at the next meeting of the class, the students should be asked to write up their results and conclusions.

Variety introduced into the management of the field trips will revive lagging interests. Take the class to a different place on each trip. Vary the procedure in as many ways as can be invented. Alternate long hikes with short trips, work the class sometimes as a whole, sometimes as small groups with student leaders, sometimes in pairs or with each student working independently. Introduce contests for the incentives that competition will provide. Plan an occasional trip for after-school hours, for the early evening (after dark), for Saturdays, or for holidays. Combine an occasional trip with a campfire supper or other woodcraft activities.

EXPLORE WITH THE STUDENTS

Many teachers feel they must know the names of all the plants and animals they may meet, and all about their biology

before they can undertake fieldwork. This misconception is probably the prime reason that not more teachers undertake to run field trips. It should be a chief function of the training of biology teachers, boy and girl scout leaders, and nature guides, to show them that a teacher is most useful not when he offers information, but when he persuades the student to make his own observations.

A bumblebee is observed gathering nectar. It requires no book knowledge to watch where it goes and how it performs at each flower. Some one of the students may know a name for the flower which the insect visits, or some of the flowers may be carried back to the laboratory where certain of the students may be charged with finding information from a flower guide in the school library. The number of visits may be counted, the class may follow the insect without disturbing it, but without losing sight of it, until they see it enter a hole in the old stone wall. There is an hour's work to do in digging out the nest, and a semester's project in transferring it to the classroom for the observation of the living colony. The student's own eyes and the available reference books should reduce the functions of the teacher to those of an executive secretary.

Trees may be identified, even if the teacher does not know their names. The characters of the leaves, the bark, the forms of the trees may be noted and compared with those of some other kind of tree. Records and actual specimens of leaves, buds, and bark may be taken back to the laboratory where reference books will provide the names around which the class's subsequent experience with the biology of the species may be accumulated. Flowers, insects, birds, other things may be identified in the same fashion. What I know about the sleep movements of plants, the identification of birds by flight, the identification of bird songs, the identification of trees at long distances, and many other such things, I have learned not from books, but from observations made in the field with my students. Boys and girls will see through any pretense to knowledge which the teacher may assume; but the interest of a class may be increased if the teacher frankly admits that he has had no previous knowledge

of the matter, but that he is ready to work out the new material with the students.

Inexperienced teachers are sometimes advised that they should not undertake to run a field trip until they have traversed the specific ground over which they plan to conduct the trip, and made themselves familiar with every plant (and animal?) which they intend to show the class. We have attended such functions—even a trip on bird foods conducted by a young lady who had planned the list of birds which were to be exhibited in a given order and in their proper feeding attitudes as the class moved through the woodland. When the actors failed to appear as their cues were called, the carefully prepared speeches had to be delivered into vacant space. It was not even such visual instruction as the textbook or wall charts might have offered. The speech on tree-feeding woodpeckers was delivered within a short distance of a flicker that was picking ants off of the ground; but the class never noticed the ground-feeding woodpecker that failed to match the prepared lecture. Previous planning might be necessary if it were the function of the teacher to demonstrate, but fieldwork acquires its greatest effectiveness only when it is a trip of exploration for both students and teacher.

MEASURE RESULTS IN QUALITY RATHER THAN QUANTITY

It is commonly objected that fieldwork provides a very slow method of acquiring knowledge. Undoubtedly many teachers who would otherwise undertake such work are deterred by visions of the quantity of material they want to cover in a year, and which they cannot cover if they spend very much time in the field. The answer to the objection is the old one, that quality is very much more important than quantity.

Come with us down the canyon. We are hunting snails in the stream. We shall see how many kinds are to be found. There is a spirally shelled species that is common everywhere. Each student compares dozens of specimens to note the individual variation, and in so doing a couple of them find speci-

mens of another but similar species, in which the shell whorls around from the left. Finally one of the boys finds a globular, distinctly different species; after which we turn from snails to the consideration of some of the other inhabitants of the stream.

It is half an hour later before one of the students discovers a very small but beautifully spiralled shell—number four on our list of snails. Now everyone finds them. One student notes that the shell is not smooth but made up of bits like the pieces of a mosaic. Suddenly one girl who has been watching her specimen cries out that it has legs! "Legs?" we ask. "Do molluscs have jointed appendages?" "No," she admits, and the class laughs at her evident error. She retires, in confusion, to continue with more careful observation. We have a discussion on the characters of snails, interrupted again, however, by the first girl who says, demurely but quite positively, "But it *does* have legs, for I saw them again, and there are six of them." Now a second student finds legs, and a head, and one of the boys breaks open the shell and pulls out a thing that is, unmistakably, an insect larva. An insect in a snail shell? What does it mean? An insect that feeds on snails? Or is it, as one of the students suggests, a case paralleling that of the hermit crab which hunts empty shells and takes up its abode in them?

But then, without microscope or dissecting instruments, two of the most clever students begin pulling the castle to pieces, bit by bit, and find the silk which holds the grains of sand together. The mystery is being solved. It has taken an hour or more to learn about three species of snails, and of the caddis fly larva that builds, out of silk and grains of sand, a spirally domed castle that rivals that of the snail in its symmetry. An expensive method of teaching, you say? But not if you value quality above quantity. Not if you think of the thirty boys and girls who, for all the years to come, will hold onto that bit of knowledge as a verity, because they have seen it with their own eyes!

P.S. We have, on several occasions since then, tried to lead other classes through that same canyon, on the same line of investi-

gation. But the trip has never again been much of a success. After the first time the students must have sensed the fact that the stage was being prepared for them. Fieldwork is most successful when it involves true exploration both for the students and for the teacher.

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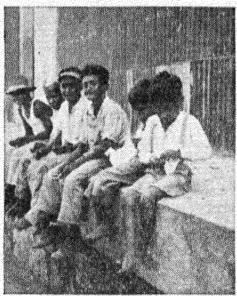
CHAPTER XVI

MEASUREMENTS AND EVALUATIONS IN BIOLOGY TEACHING



IN THE TEACHING OF BIOLOGY, JUST AS in any other sort of teaching, one is justified in giving examinations to the students: 1. As a means of encouraging specific accomplishment. 2. As a means of informing the students where there are deficiencies in their work. 3. As a means of letting the teacher discover the extent to which his teaching has been a success or a failure. 4. As a means of determining the merit of each student in comparison with the merits of the others in the class.

It is sometimes suggested that it would be more democratic to avoid evaluations, and that more independence will be developed among the students if they are allowed to get what they want and are not asked or required to take anything more. But such a *laissez-faire* doctrine ignores the realities of the universe —of human nature and of the learning process in particular. Even though we must depend upon a student's own interests to set him to work, there are few of us who do not drive ourselves more effectively when we have assumed a definite task to be completed by a definite time. This self-propelling force is especially effective if it involves a contract made with some other person who is also interested in the completion of the work. Class examinations set the specific stints, set the time by which the work is to be completed, and involve a contract between the teacher and the student. In consequence, good

teachers have always used examinations and they will undoubtedly continue to use some means of testing those whom they are teaching.

The relative merits of the various types of tests which may be used in any sort of teaching have been debated so often that it would appear unnecessary to do more than summarize the material as it applies to the teaching of biology.

OLD- VERSUS NEW-TYPE TESTS

In the older types of examinations, the students are asked to frame definitions, to repeat facts which they have memorized, to describe materials which they have observed, or to discuss the significances of the facts, principles, or other data which they have acquired. Which of these several aspects is most emphasized varies with different teachers, with the subjects involved, and with the particular circumstances under which the examinations are given. Consequently the efficacy of such examinations varies widely. This fact constitutes a valid objection which is commonly raised against old-type examinations. Students of educational measurements estimate that the correlation between the grades obtained from such tests and the quality of the later performances of the student may be represented by figures ranging from 0.2 to 0.95 (where 1.0 represents perfect correlation). The effectiveness of any particular examination is therefore of uncertain value; but it may have more value than current opinion would ordinarily grant.

That the deficiencies of these examinations are also due to difficulties in grading them on a purely objective basis seems at least in part a fair criticism.

That the new-type tests (true-false, multiple-choice, matching, completion, range of information, etc.) provide a more objective basis for grading is also a fair statement to make. And these tests enjoy a wide popularity because of the facility with which they can be given and graded by the instructor or even by an unskilled assistant. There is certainly something to be said for any device that reduces the work of an already over-

burdened teacher; and the grading of an old-type test demands a great deal of time.

But there are several objections raised by science teachers against the new-type tests. First of all, it is objected that even when well made, they test little more than the student's ability to memorize specific data. And it has repeatedly been said that teaching should be concerned with something more than the quantity of facts acquired!

It is objected that the new-type tests too often measure nothing more than the student's ability—or good fortune—in guessing. While an expert administration of the tests may avoid this complication, some of them (particularly the true-false and multiple-choice tests) are so easily beaten by the outright gambler, and so difficult to guard from mere guesswork, that it is a grave question whether they can be used with safety by the average teacher. The cases where specialists in education have been duped by bright adolescents taking such examinations are too many to be lightly dismissed.

Another objection to the current tests in biology (and probably in many other subjects) is their expectation of replies which are downright distortions of fact. This difficulty sometimes originates in the test-maker's ignorance of the science. Sometimes it is due to the fact that the test has been modeled on a particular syllabus or textbook which makes no allowance for the differences in materials, organization, emphasis, and interpretations in other books. Of the several new-type tests which are now available in biology (see the list at the end of this Chapter) there is hardly one which is not open to criticism on this count.

The available tests are also inadequate because they expect clear-cut answers for problems which do not allow definite solutions. Not all things are black or white; neither yes nor no will constitute correct answers to all the questions that may be asked; and the statements offered in a true-false test are sometimes neither entirely false nor entirely true. In multiple-choice tests it is common to find two or more statements that are equally good, and sometimes no statement that would be acceptable to one who really knows biology. In matching tests, an experienced

biologist may find a half dozen replies to a question for which the tester will accept only a single solution. Completion tests and range of information tests are not as open to this last criticism, though they may be criticized on other grounds. Tests asking for the identification or labeling of parts of drawings often have the figures so crudely drawn that expert biologists are unable to identify the plants, animals, or structures involved.

The following instances quoted from published tests, or from tests that have actually been used by educationists, may indicate why so many scientists are unenthusiastic about these "scientific measures of science teaching." It is claimed that new-type tests have a coefficient of reliability which ranges between 0.7 and 0.9; but such instances as the following make one question whether the coefficient is anything more than flat zero. For the particular items quoted below it is certainly something less than the average for the older types of examinations.

In the multiple-choice tests the student is allowed only one answer as correct. But in the following, at least 2 answers are in actuality correct:

An evergreen tree valued as an ornamental shrub is the (lilac—sumac—hemlock—blue spruce).

Spiracles are (pimples—holes—projections—hairs—breathing-pores).

Due to their isolation mountain people are (very healthy—very glad to have visitors—peculiar).

The distinguishing feature of the mammals is the possession of (backbone—hair—two pairs of legs—milk glands—nervous system).

A large quantity of paper is made from the pulp of (oaks—poplars—walnuts—bones—cornstalks).

A part of the pistil of a flower is the (filament—pedicle—bract—ovary—anther).

Mandibles are a kind of (fins—swimming organs—gills—breathing pores—mouthparts—pincers—antennæ).

Insects breathe by means of (gills—bronchi—lungs—tracheæ—alveoli).

No two animals are ever exactly alike. This is in accordance with the law of (heredity—dominance—variation—isolation—segregation).

Insects have the following number of pairs of wings: (one—two—three—four—five).

The embyro of a plant is contained in the (roots—seed—ovule—pollen—ovary).

In the following examples, at least 3 answers are in actuality correct:

Soil is protected from erosion by (vegetation—irrigation—reclamation—fertilization—cultivation).

All forests must not be destroyed because (we need the leaves, acorns, and needles—they are pretty—we need the shade—they save our water supply).

Mosquitoes can be eliminated by (swatting them—destroying breeding places—smudges—poisons).

Digestion is aided by (hormones—enzymes—toxins—vitamins).

The part of the eye that regulates the entrance of light is the (pupil—iris—retina—eyelid—lens).

Chemical substances used to destroy insects are called (powders—insecticides—emulsions—germicides).

Katydids are relatives of the grasshopper and cricket because they (sing—have exoskeletons—have straight wings—have direct development).

Some states try to protect the farmer against the corn borer from other states by (fumigation—inspection—boycott—quarantine).

A modern invention that aids in forest preservation is the (microscope—airplane—fire extinguisher—telescope).

A good example of a plant having modified leaves is the (pitcher plant—elm—clematis—poplar—elephant ears).

The part of the flower which often attracts bees is the (calyx—corolla—stamens—pistil).

Bacteria are of great importance to farmers because (they are so small—they multiply so rapidly—they sour milk—they have the power of nitrogen fixation).

The flowers of the composite family are in (heads—racemes—umbels—spikes—catkins).

In the following, all of the answers are in actuality correct, although the student is judged deficient if he selects any answer except the one the experimenter happens to want:

Plants are developed primarily by means of (seeds—roots—grafting—cuttings—transplanting).

Many orders of insects are classified according to (the number of legs—the wing structure—the body regions—the kind of mouth-parts).

Biology is useful to man because (it teaches him to understand and control life—a knowledge of it helps him to earn more money—he gets credit for studying it—it is interesting).

Glaciers are composed of (sediment—rock—vegetation—ice—soil).

A river influenced by the drainage of forest lands is the (Hudson—Platte—Mississippi—St. Lawrence).

Ants are sometimes harmful because they (build runways in the earth—eat holes in timber—protect plant lice—get in sugar).

Respiration takes place in the (cells—lungs—gills—skin—blood).

The colored parts of a flower are (sepals—petals—pistils—stamens—corolla).

In the following, none of the answers is correct, although the student is judged deficient if he does not select one, and that particular one which the experimenter happens to want:

The development of embryos from fertilized eggs is termed (reproduction—mitosis—hermaphroditism—symbiosis—parthenogenesis).

The leaves of the northern evergreen trees are narrow to prevent (excessive photosynthesis—excessive evaporation in winter—destruction by animals—being broken by the wind).

The vitamins found in oranges, lemons, raw carrots, onions, and apples are classified as vitamin (A—B—C—F).

Alcohol is not a food because it (contains no protein—produces heat—oxidizes very rapidly—hardens the tissues).

In the following, one alternative is such an insult to the intelligence of any high school student that it is useless as a measuring rod. At least 2 answers are correct.

A fly is (an animal—a fish—an insect—a reptile—a building).

Gypsy moths may be destroyed best by (collecting egg masses—using moth balls—shooting the adults—spraying the trees).

In the following, the answer is dependent upon geographic factors. The number of correct answers in the state of Maine, for instance, would be quite different from the number correct in any state south of the Ohio River.

Mosquitoes should be killed because they (bite us—get into our food—may carry malaria—keep us from sleeping at night).

A northern summer resident is the (quail—crow—oriole—junco).

In the following completion tests, incorrect or highly debatable answers are demanded by the key accompanying the test:

The robin is primarily . . . [*a seed eater* is the answer demanded].

The earth is the center of . . . [the solar system!].

The greatest enemy of forests in the United States is . . . [man?].

The process that does not destroy the nutritive qualities of milk but that does destroy disease germs is named . . . [pasteurization?].

In the following matching tests, only one answer is supposed to be correct; but the several that might readily be taken to be correct are indicated in the parentheses:

An agent of distribution of the oak is . . . (rivers—birds—squirrels—furry animals).

Shingles are made from . . . (carefully selected hickory stems—a plant that grows in Virginia—thin boards of red cedar).

Weeds are successful in the struggle to grow because . . . (they are climbing plants—they have good methods of seed dispersal—they can withstand very unfavorable conditions).

Bacteria are classed as Thallophytes because . . . (they reproduce by budding—they have no chlorophyll—they have no roots, stems, or leaves).

In the presence of tasty foods our mouths become filled with saliva. The biologic phenomenon represented is . . . (reflex—metabolism—adaptation—specialization—irritability—secretion—stimulation—natural selection).

The flower-head of the dandelion closes after the sun has gone down. This is an example of . . . (reflex—metabolism—transpiration — tropism — adaptation — specialization — irritability — natural selection — turgidity — phototropism — thermotropism — sleep movements—hydrotropism). [*The experimenter explains that he did accept a second answer as correct!*]

The normal temperature of our body does not rise beyond 98 degrees on the hottest day. This is an instance of . . . (reflex—metabolism—adaptation—circulation—specialization—irritability—stimulation—perspiration). [*Here again, a second answer was allowed as correct!*]

Since, in biology teaching, it is a prime aim to interest students in the living world through which they move, and to inspire in them some respect for the scientific method, it is desirable to measure:

1. The amount of factual material which the student has memorized.
2. The student's understanding of the facts.
3. The extent to which he has developed scientific attitudes.
4. His ability to reason accurately.

We shall, then, want to know how far the old- or new-type tests, or a combination of the several tests, may go in the measurement of the four items noted above.

MEASURING FACTS MEMORIZED

The memorization of factual material is the one end which all teaching has in common. While it may be of secondary importance in science teaching, it remains a necessary part of learning even in this field.

In attempting to measure this factual learning the older types of examinations ask for definitions, repetitions of memorized facts, and descriptions of material observed. Similarly, all of the new-type tests test this quality, and it is on this point that they are particularly efficient.

But the definitions and descriptions asked for on an old-type test demand more extensive memorization than is ordinarily required in a new-type test. On the other hand, the new tests can be administered and graded more efficiently and they may, in consequence, cover a larger number of items in an allotted time. The new tests, if well made, and if correctly applied, may provide more objective bases for grading the student. The new tests, if well made, are therefore to be recommended for short quizzes and for that part of the more thorough examination which may be concerned with measuring the student's store of memorized material.

TESTING THE STUDENT'S UNDERSTANDING

But a parrot-like ability in repetition is no evidence of one's understanding of what he repeats. Do these terms and definitions which the students give represent anything more than rote memorization?

The old-type tests attempt to measure understanding by asking the student to frame definitions in his own terms, to explain what he has defined, and to discuss a topic at some length. There has been too great a tendency to forget the extent to which these tests do accomplish these ends. It is doubtful if any of the new-type tests come as near to discovering the student's true understanding of his material. Whatever the other objections to the

old-type tests, their value in measuring understanding is enough to warrant their frequent use.

The oral quiz is better than any written test as a means of measuring understanding. As every salesman, horse-trader, and good teacher must realize, there is no way of finding out what people really know better than that afforded in face-to-face conversation with the prospective victim. By noting the tone and the promptness of the reply, and the whole bearing of the student, the observant teacher may be able to judge how much understanding is back of the words in the answer. Any doubt in the teacher's mind can be cleared by a second question leading from the first. Sometimes the side-issues touched upon in such secondary questions are better tests of the student's understanding than the original set prepared by the examiner.

The value of the oral examination is known to those who are preparing students for advanced degrees, or students who are seeking special honors in college courses. But oral quizzes impose a considerable burden upon a teacher who is asked to match wits with a young student, and this may be some explanation of the decadence of the method, especially in the colleges.

It is also true that oral quizzing is difficult to manage with a large group of students. In the usual recitation, the body of the class is too often left to its own day-dreaming while one student occupies the teacher's attention. It is, moreover, to be objected that it is peculiarly difficult to grade objectively in an oral quiz, because the personal contact which obtains between the teacher and the student allows something more than the latter's knowledge and understanding of his material to enter into the grading.

There seems, then, no ideal way to test this understanding of memorized material. Perhaps some use of all the available methods is better than an exclusive dependence on any one. A combination of old- and new-type tests and oral examinations may catch the fourflusher who pretends to know more than he does know, and discover the timid one who knows more than his first answer would indicate. But we do not yet know how accurately this item of understanding can be measured.

EVALUATING SCIENTIFIC ATTITUDES

Since we are concerned with introducing students to this living world, we should like to know the extent of the interests we have aroused in them. Since we are trying to develop their respect for the scientific method, we should like to know what evaluations they are putting upon observation, and to what extent they are basing their reasoning on observed data. These interests and respects are the things with which we are most concerned in science teaching.

There seems to be none of the new-type tests which evaluates the quality of a student's attitudes. They are, at best, measuring rods of quantity learned. The evaluation of student interests must be made by some means other than new-type tests.

The old-type tests do seem to provide some opportunity to find out how far students have become interested in the materials of the course. In such tests an occasional question is designed to give the student an opportunity to express his interests and attitudes, to choose between observed data and authority, or between good and bad authority, or to tell where he would go for the answers to the biologic problems which are set before him.

Further than that, the teacher's daily contacts with the student, in and out of class hours, may give him even better opportunities to measure interests and attitudes. In the course of those contacts, the student may expose his inner self, his emotional reactions, and his evaluations of scientific attitudes.

But it is objected that such evaluations should not enter into grading systems or even be taken as tests of what one has accomplished in his teaching. Evaluations are obviously subjective, and it is said that we need objective measurements of these things. This contention, however, involves the usual confusion of the terms measurement and evaluation. Physical phenomena may be measured, but merit is an esthetic quality that must be evaluated. The winner of a swimming race can be determined with a measuring tape and a stop-watch; but the quality of the diver's performance is to be determined by averaging the sometimes

widely divergent opinions of several judges. In all evaluations, whether in the athletic contest or the teaching of biology, we must be satisfied with subjectively set standards. In matters of art, there is no other way of determining merit (see Chapter IV).

TESTING SCIENTIFIC REASONING

The characteristics of scientific reason are its dependence on observed data, and the simplicity of its logic. The science teacher would like to know the extent to which he has inculcated these qualities in his students.

Most of the new-type tests do not seem to test the student's ability to reason. Only matching tests and multiple-choice tests may touch on this ability, but they could probably be made more effective in this direction.

The old-type tests often do demand discussion answers which will bring out something of the student's ability to reason.

But the outstanding means for testing reasoning ability is the problem question. As a teaching device it is at least as ancient as Socrates, though there are indications that it is about to be rediscovered as a new-type test. The device has had more or less extensive use among science teachers for many years. Through the problem question the student is presented with a situation which he has not previously met in the classroom studies, although the problem becomes more interesting if it involves everyday material with which he has had some previous contact. The student is asked to identify the biologic principles which are involved in the problem, and to apply his knowledge of those principles in arriving at the solution. The device is thus a test of the extent of the student's knowledge, his ability to draw on his knowledge, and his ability to put his data in a logical sequence which will lead to sound conclusions.

The following are examples taken from the author's *New Introduction to Biology*.

1. Farmers often store corn-stalks for winter feeding of cattle by cutting them into small pieces and packing them tightly in a

tank-like structure called a silo. Why is it that the food does not spoil in a silo? (*The solution depends on a knowledge of bacteria of decay and their dependence on oxygen, and on an ability to put this knowledge in logical order.*)

2. Which of the following would you expect to have large ranges: a dandelion, a snake, a rabbit, a rat, a cockroach, a nut tree, a thistle? (*The solution involves a knowledge of the adaptive structures which might aid in the spread or restrict the ranges of these particular organisms, and of the organic, climatic, and other environmental factors which would affect them.*)

3. Which of the American life zones were the last ones to be settled by Americans? Name the factors that prevented their earlier settlement. (*The question demands a little knowledge of history, a considerable knowledge of American life zones and of factors of distribution in general, and an ability to select those factors which apply to men living in our type of civilization.*)

4. If you were a deep-sea animal that could think, what would you consider the most peculiar features of the environment in which land animals live? (*This calls for a knowledge of the essential characteristics of both land and deep-sea environments, and an astute ability in comparing their effects on animals.*)

5. Why do gardeners wait until the leaves are off of shrubs, or pick them off, before they transplant them late in the fall? (*The answer must depend on a knowledge of stomata, root hairs, the nature of sap circulation, etc.*)

6. A fine wire, tightly twisted about a tree trunk, may (if it does not kill the tree) cause a swelling of the trunk on one side of the wire. Will the swelling develop above or below the wire? Explain. (*This question requires a considerable knowledge of plant structure, and a detailed knowledge of sap circulation.*)

7. Cut flowers may be kept fresh for a longer time if a little salt is added to the water in which they are placed. Explain. (*Does the answer depend on phenomena of osmosis, plant feeding, decay, or something else?*)

8. Will dried fruit swell more when cooked with or without sugar in the water? And how could dried fruit be cooked down to a sauce? (*Do you understand osmosis well enough to apply it to this everyday problem?*)

9. Would it be a better or a worse place in which to live if all the rodent pests were exterminated from your state? (*The answer involves a specific knowledge of the activities of rodents, and of all the other creatures concerned in the same ecologic niche, and calls for clear ideas on the significance of an ecologic balance. Incidentally, the question is one which is assuming national importance, with diverse solutions offered by different groups.*)

10. Why are the National Forests mostly in the Far West? Would State and National Forests be as important in the East? (*This question involves the whole conservation problem; its solution calls for a considerable knowledge of forest ecology.*)

11. Might there be a relation between the birds of Pennsylvania and the height of the Mississippi River in Louisiana? (*This question involves a considerable knowledge of bird, insect, and forest ecology, and demands common sense in applying the data to a particular instance.*)

12. Is a specialist or a jack-of-all trades more valuable to present-day society? (*This question calls for a clear understanding of the nature of a society, and should indicate that sound evaluations may depend on more data than are ordinarily available.*)

It may be added that problem questions have the aspect of being puzzles, and their solution consequently captures the student's interest at the same time that they are serving to test him.

Problem questions may be included in any type of examination, they may be the subject of class discussion, or they may provide material for home study. Good problem questions are not easily prepared, and the biology teacher might well collect them from year to year until he has a stock large enough to test the class on a wide variety of biologic principles.

In order, then, to check all of the ends of one's teaching, it would appear necessary to use, in various ways and on various occasions, a combination of all methods of testing: the old-type test in all of its forms, the various new-type tests, oral quizzing, problem questions, and even such general impressions as may be obtained in daily contacts with the students.

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* Recommended as the best references for student use.

CHAPTER XVII

TEACHING PROBLEMS IN TAXONOMY

A HALF CENTURY AGO THE NAMING AND CLASSIFYing of plants and animals constituted nearly the whole of the elementary course in botany and a considerable part of the course in zoology. Subsequently it was almost completely replaced by morphology, and later by some of the other sciences of biology. The only taxonomy left in most cases was a bare outline of the classification of the major groups of plants and animals, usually presented as one of the most uninteresting ends of the year's work.

OBJECTIVES

Taxonomy, however, may well be emphasized in elementary teaching, for it may contribute materially toward the vitalization of the biology course. The aims of biology which are especially served by this unit are:

1. **To interest students in the world about them.** It is the whole panorama of plants and animals, three million species of them, which is to pass in revue in this unit. Circuses never offered more variety. If the unit means nothing more than a classification to be memorized, it is because the teacher's vision ends with pickled and preserved specimens instead of this living world out-of-doors. Well taught, the unit is especially effective in accomplishing the first end of the course—interesting students in the living world about them.

2. **To contribute to one's list of friends in the world.** With this unit the student is introduced to the common species of the local fauna and flora. Around the names which he learns for these plants and animals he may subsequently gather memories of all the out-door trails which he will ever travel. Song sparrow and cardinal, chickory and sweet gum, will be more than names in a scheme of classification to him. There are endless such names, of other birds, of insects, of mosses and of lichens, of trees, of turtles, of toads, and of flowers, which may come to mean a thousand things to these boys and girls to whom we are introducing the out-of-doors.

Will it be possible to measure the efficacy of the teaching in this subject? Is there a new-type test, or an old, which can evaluate a unit that can turn a lonely world, and a dreary one, into a store of treasures and friends? Surely it is a rare opportunity that we have in teaching this unit of taxonomy.

3. **To present the scientific method through a system of classification.** Science has been defined as systematized knowledge, and a biologic classification, dealing as it does with an inconceivable number of items, beautifully illustrates the meaning and convenience of systematized facts. There is a beauty in a complete and yet simple classification which even the beginning student can be led to see.

4. **To provide a basis for the classification of all biologic data.** The main groups in a taxonomic classification are the pigeonholes into which all the facts of morphology, physiology, genetics, ecology, and the still other sciences may be stored. In this sense, taxonomy is basic to all the other units in a biology course.

SUGGESTED CONTENT

Taxonomy

1. Classification, noting the distinguishing characteristics and general biology of:

   Plants, arranged from the highest to the lowest:
   - Seed plants
     - Conifers

- Common seed plants
  - Monocotyledons
  - Dicotyledons
- Ferns and allies
- Mosses and liverworts
- Thallus plants
  - Algæ
  - Fungi
  - (Lichens)

Animals, arranged from the lowest to the highest:

- Protozoa
- Sponges
- Polyps and medusæ
- Flatworms
- Roundworms
- Segmented worms
- Arthropods
  - Crustacea
  - Horseshoe crabs
  - Arachnids
  - Millipeds
  - Centipedes
  - Insects
- Molluscs
- Vertebrates
  - Fish
  - Amphibia
  - Reptiles
  - Birds
  - Mammals

Organisms neither Plants nor Animals:

- Slime molds
- Diatoms
- Bacteria
- *etc.*

2. Methods in Taxonomy:
   - Naming
     - Importance
     - Use of binomials
     - Use of Latin
     - International Rules of Nomenclature
   - Classifying
   - Showing Relationships
   - Methods in Making Taxonomic Explorations

LABORATORY PROBLEMS IN TAXONOMY

The page references are to the detailed outlines in the author's Workbook in Biology.

Living Things (p. 3)
Alternation of Generations (p. 7)
Review of Plant Classification (p. 9)
A Census of Conspicuous Plants (p. 11)
Review of Animal Classification (p. 15)
A Census of Conspicuous Animals (p. 17)
Tree Species, Genera, and Families (p. 19)
Insect Species, Families, and Orders (p. 21)
Mounting an Insect Collection (p. 25)
Taxonomic Keys (outline form) (p. 27)
Taxonomic Keys (dichotomous form) (p. 31)

FIELD PROBLEMS IN TAXONOMY

Out-of-doors (p. 1)
Plant Groups (p. 5)
Animal Groups (p. 13)
Tree Species, Genera, and Families (p. 19)
Species and Genera in the Composite Family
Insect Collecting Trip (p. 23)
A Discovery Game (p. 33)
A Single Species of Tree
Conifers
Cultivated Conifers
Tree Identification by Leaves

Tree Identification by Bark
Tree Identification by Branches and Buds
Tree Identification by General Form
Tree Identification by Autumn Colors
Tree Identification by Fruits
Economic Values of Common Trees
A Street Shade-tree Survey
Bird Identification by Plumage
Bird Identification by Flight
Bird Identification by Songs and Call Notes
Bird Identification by Nests
Flower Identification (many trips)
Insect Identification (to families)
Common Fungi
Mosses and Lichens
Families of Cultivated Flowers

SPECIAL TEACHING PROBLEMS IN TAXONOMY

1. **Basing the unit on fieldwork.** Successful teaching in this unit will depend to no small degree on the amount of fieldwork included. Thus linked with the out-of-doors, the unit may contribute all we have envisaged for it in interesting students in the world of living plants and animals. The suggestions for field trips given immediately above will indicate the many possibilities for such work. Some of this fieldwork should be feasible even for city schools (see Chapter XV).

2. **Sequence among other units.** The demand for fieldwork places the unit either in the early fall or late in the spring. In most regions there is no other effective place for it. It must not be shifted to any other position in the course if it is to contribute all it can toward accomplishing the ends of the teaching. The significance of the unit as a basis for cataloging all other biologic data also bespeaks its early position in the program.

3. **A year's project in systematics.** If, as we have already suggested, this unit is to introduce the student to the joys of an intimate acquaintance with plant and animal species, considerable time must be given to the gathering and identification of data

or specimens of at least one group of common plants or animals. This calls for work extended over a period of time, and involves more field observation than will be possible in that portion of the semester which might fairly be assigned to taxonomy. Therefore, after the class has completed the textbook and laboratory work normally allowed for this unit, it should undertake a special study of some single group of common plants or animals. Trees, birds, flowering plants, insects, and still other groups are available for the study. The work should constitute a class project, carried along by the independent observations of each student, and extending throughout the whole of the school year.

Thus, if trees are chosen for such a study, the first trips on tree identification might be run with the whole class in the course of the regular work in the unit on taxonomy. After that unit is completed, and while the class in its recitations, textbook, and other work is engaged with the study of other units, each student may still be asked to observe trees in the course of his everyday, out-of-class activities. He may keep a notebook, recording the distinctive characters of all the species which he finds and learns to identify, adding whatever he observes concerning the biology of each kind of tree. Reference books on trees may be provided for the use of the class. The teacher may encourage the work by helping the students individually. Once a month (or oftener) the whole class may leave its scheduled routine to report on and to discuss the material which they have gathered. The students should know that they are to be tested and graded on the number of trees that they can successfully identify (in practical tests in the field), and also on their acquaintance with the biology of the species so identified.

If an element of contest is introduced into the making of the notebooks and the field tests, a class can be kept interested in such a long-time project extending throughout the school year. Having learned to identify thirty or forty species of trees which they have watched from early fall until late spring, the students should be convinced of the lasting pleasure that may be derived from such studies. Many of them may want to continue their observations on trees or on other groups into later years, thus

finding interests which may serve as hobbies while they pursue their various paths as average citizens.

4. **Technical names.** In the present unit and in morphology there are more technical terms than elsewhere in biologic science. In order to reduce the difficulties occasioned by this nomenclature, it was urged (Chapter II) that the Latin binomials be replaced by English names in an elementary class. This applies both to the high school and to beginning classes in the college.

The same avoidance of technical terms may be recommended even in the consideration of the main groups (the phyla, classes, orders, etc.) of plants and animals. Here, unfortunately, the question is complicated by the fact that there are no convenient English names for some of the groups. Nevertheless the English names of most of them are better established, even among scientific men, than the technical equivalents. The English words fern, moss, roundworm, flatworm, fish, and bird are used a dozen times for every time that Pterodophyta, Bryophyta, Nemathelminthes, Platyhelminthes, Pisces, or Aves appear in the everyday conversation of biologists. And while such terms as Coleoptera, Diptera, Arachnida, Gastropoda, etc., are not precisely covered by beetles, flies, spiders, and snails, their equivalence seems close enough to warrant their use with beginners. The outline of this unit, given above, includes the English terms which have proved convenient both in high school and elementary college teaching.

5. **Details of classification.** The barest minimum of general classification is assuredly all that the elementary student needs. Of the fifteen or more main groups of animals, ten or even eight will include all that he is ever likely to meet outside of the classroom. Of the fourteen or more classes of arthropods, five or six will include ninety-nine and ninety-nine hundredths of every hundred that the average person will ever see. For the professional biologist there is often great significance in these infrequently-met groups, but to burden the average beginner with anything except the most important portions of the classification is to forget the real purposes of science teaching.

6. **Organisms neither plant nor animal.** Traditionally, of course, there are no such things—all organisms must, *a priori,* belong either to the plant or to the animal kingdoms. If other organisms are mentioned, one is immediately asked for the name of this "third kingdom." The answer is that there are several groups of organisms that are neither plants nor animals; that in most cases they are probably closer to the primitive forms of life than anything which is definitely plant or animal; that some of these groups may be ancestral to the present-day plants and animals, or similar to the ancestral stocks from which the two great kingdoms were derived; but that most of these are groups which have developed in their several directions independent of plant or animal lines of evolution. While all of this has been understood for a long time by the special students of classification, even college teachers (most of whom are not taxonomists) have shown a curious reluctance to accept the meanings of these studies. We still persist in cramming every living thing into one of the two kingdoms, debating whether the college department of botany or of zoology should teach the slime molds, the sporozoa, and the other odd groups. On the other hand, beginning students in high school, as well as in college, find it easy to understand this problem in classification, and develop considerable interest in these groups as fundamental elements in the story of the origin of life.

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CHAPTER XVIII

TEACHING PROBLEMS IN DISTRIBUTIONAL BIOLOGY

DISTRIBUTIONAL BIOLOGY IS ONE OF THE newer sub-sciences. The data are in consequence buried in the technical literature, and only a few of the more recent texts have offered anything in this unit, in either the high school or the college fields. The delayed development of the science is due to the great difficulty of securing data in the quantity necessary for the solution of the problems involved. The collection of thousands of specimens of each species, from scores of different localities, may involve work spread over many years and ultimately give generalizations concerning the range of only a single species. But these difficulties in acquiring the research data are no measure of the value of the material for beginning students, for here is a unit which, properly taught, may be one of the most interesting in a live course in out-of-door biology.

OBJECTIVES

This unit may make a unique contribution to one's enjoyment of the world through which he travels. With some knowledge of the factors controlling the distribution of plant and animal species, the average man will find the changing panorama of living things among the most interesting phenomena to be observed on a cross-country journey.

In this day of cheap second-hand cars and superb highways, every boy and every girl, even those of the most cramped city streets, may expect to travel, some day, into life zones differing from those in which they were born. Then the trip to Florida or to California, the ascent of a mountain peak, even the frequently-made journey to the nearby big city may become something more than miles to be endured to the end of the journey. Without knowing precise names for any of the species, even the average citizen can see that the deciduous woods have given way to evergreen forests, that these disappear in treeless grass lands, that desert shrubs flank the base of the approaching mountains, and that new kinds of evergreens are in the mountain forests. With the background of an introductory biology course, he may recall the significances of rising mountains, advancing ice-sheets, and Asiatic invaders, and may try to find out more about the story involved in the particular fauna and flora through which he moves.

Even the familiar things at home are parts of a whole world of invading faunas and floras. Here in Indiana for example, are southern birds that reach their northern limits in our region, northern species that visit us only in the winter, far northern things that get this far south only in an unusually bitter season. Among the conspicuous trees of the area are the persimmon and yellow oak, and still other things from the Southland. Here is another oak which finds its chief distribution in the Ozarks, and a "tulip tree" which has its only close relatives in eastern China.

The weed lots grow an astounding assemblage of globe trotters: English plantain, dandelion, chickweeds, wild lettuces, and many others have come to us from Europe. Similarly, chickory has strayed into the region in recent years. There are hemlocks on the neighboring hillside, even in this southern end of the state. They spell north country and tell the story of ancient ice sheets which came southward almost to the town in which we are living. There are sunflowers and ground squirrels which are migrants from the plains to the west of us. There are—endless things right at home, and their histories may be read by the boy and girl who is given some introduction to the principles of distribu-

tional biology. They will find the world more interesting because of this unit in the biology program.

SUGGESTED CONTENT

Distributional Biology

- Ranges
  - Facts. Each species is restricted to a range which is:
    - Usually limited in extent
    - Irregularly bounded
    - Ordinarily continuous
    - Enlarged and decreased in the course of time
  - Factors. Ranges are limited by:
    - Organic factors
    - Geographic factors
    - Climatic factors
    - Geologic factors
- Life Zones
  - Definition
  - Doubtful reality
    - *E. g.* American life zones
    - *E. g.* In mountain areas
- Regions of the World
  - North American
  - South American
  - Eurasian
  - African
  - Oriental
  - Australian
  - Arctic
  - Antarctic
  - Oceanic

LABORATORY PROBLEMS IN DISTRIBUTIONAL BIOLOGY

The page references are to the detailed outlines in the author's Workbook in Biology.

Ranges of Pacific Coast Organisms (p. 35)
Ranges of Eastern American Organisms (p. 41)

Life Zones (p. 47)
Geographic Factors of Life Zones (p. 49)
Arctic-Alpine Areas (p. 53)
Life Zones and Regions (p. 55)

FIELD PROBLEMS IN DISTRIBUTIONAL BIOLOGY

Imported Plant Species as Pests
Variation in Northern and Southern Species Hybridizing in a Region (*if located near boundaries of life zones*)
Sources of Garden Plants (especially in rock gardens)
Introduced Weeds
Pond Zonation

SPECIAL TEACHING PROBLEMS

1. **Possibility of elementary laboratory work.** The difficulty in finding laboratory work in this unit originates in the fact that first-hand observations in the science are to be gathered only by explorers who travel long distances to secure the specimens, and by taxonomic specialists who determine the correct names for the collected material. But these accumulated data can then be taken by the beginning student and put together to lead to generalizations illustrative of the principles of distribution. The data are for the most part buried in the research literature and unavailable for class use, but the laboratory problems cited above do make an effective set for elementary students. These problems, in actual practice, prove strikingly successful in arousing the beginner's interest and in illustrating the principles of the science.

2. **Does the unit involve too much detail?** There are reports that students find the unit difficult or monotonous. This is apparently due to the inclusion of too much detail. If classes are asked to memorize the location and precise boundaries of a lot of American life zones into which they have never gone, and to remember a long list of species characteristic of each zone, the teaching becomes very academic—mere memory drill instead of training in science. Interest may be developed by emphasizing

the facts and factors of distribution in general; analyzing the factors involved in such zones as are studied in detail; drawing on the first-hand experience of those students who have at some time gone into a life zone other than the one in which the school is located; using an abundance of visual illustration (see the References given below); and centering the study chiefly on that life zone in which the school is placed, and on the life zones immediately adjacent to it. The text should be used as a reference geography to which one goes for the data on questions which have been raised in the class.

3. **Position in the sequence of units.** The data of distributional biology are being gathered by the exploring taxonomists, and the unit logically follows taxonomy. The study of the factors of distribution is related to the ecologist's analysis of environmental effects on organisms, so it would also be logical to place the unit after that on ecology. But neither taxonomy nor ecology are necessary pre-requisites of an elementary consideration of distributional biology.

There are no seasonal factors involved in the placement of this unit unless one undertakes fieldwork. In the later case a fall or late spring position is desirable.

REFERENCE LIST IN DISTRIBUTIONAL BIOLOGY

There are almost no convenient summaries of distributional biology, either in the texts or in special volumes, that are at once general and scientifically sound. The summary of the science in the author's own text is based upon years of first-hand research in this field. Among the other references, there are the pamphlets which are obtainable at little expense from the U. S. Government Printing Office, and gratis from many Chambers of Commerce, and these will prove usable with high school classes.

In Texts

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* Recommended as the best book for student use.

CHAPTER XIX

TEACHING PROBLEMS IN MORPHOLOGY

THIS IS THE MOST COMMONLY USED unit in the elementary course, with an abundance of easily managed laboratory work. It thus becomes important to consider the objectives of the unit, selecting that portion of the material which is best adapted to serving the ends of the biology course as a whole.

OBJECTIVES

It is commonly emphasized that some knowledge of structure is fundamental to an understanding of function (physiology) and of some other aspects of biology. While this significance of morphology has undoubtedly been exaggerated, especially as far as it applies to work with beginning students, it is quite true that one soon comes to a place in the teaching of biology where some conception of the meaning of cell, tissue, and organ, and even of some of the special structures of higher plants and animals, is requisite for an understanding of other fields. Some morphology is particularly necessary before genetics is studied; and the sequence in which the units are placed must take this into account.

The materials of morphology are very tangible, more so than the materials in most other units, and they are thus excellent for teaching the scientific method. This is some warrant for introducing more than the normal amount of laboratory into the

unit, though not for building the whole year's work around dissections.

Some students are very much interested in seeing the structures involved in the workings of plant and animal machines. Thus the unit may satisfy the objective of interesting students in the living world; but there is danger that others may find this material less interesting, and this is one of the questions dealt with in the following discussion of teaching problems.

SUGGESTED CONTENT

The following outline tries to emphasize principles while allowing less time than is usually given for the consideration of the special morphology of particular forms. The most promising suggestion for a modification of the material is for the union of morphology and physiology as one unit. So far the attempts that have been made to do this in the general biology course do not seem altogether satisfactory, although the combination is often well made in the study of such special groups as insects, higher vertebrates, vascular plants, etc.

Morphology

- Structural Units
  - Organs
    - *E. g.* Systems of organs in higher animals
    - *E. g.* Tissue organs of higher plants
  - Tissues
  - Cells
- Special Examples of Structures (to be studied primarily in the laboratory)
  - Higher animal structures
    - *E. g.* Grasshopper
    - *E. g.* Earthworm
    - *E. g.* Frog
    - *E. g.* Human

Higher plant structures
  In leaves
  In stems
  In roots
  In flowers
  In seeds and fruits
Origin and Development of New Individuals (Morphogenesis)
  Reproduction (morphology and physiology)
    Asexual reproduction
      Cell division, spores, etc.
    Sexual reproduction
      Germ cells (eggs, sperm)
      Fertilization
      Care of eggs and young
  Embryology
    Origin of the new individual as a single cell
    Cell division
    Organ differentiation
      E. g. In germ layers of higher animals
      E. g. In seedlings of higher plants
    Recapitulation
    Feeding the embryo
      E. g. In seed plants
      E. g. In birds
      E. g. In mammals

For college courses, more details may be introduced throughout this program; a larger number of microscopic preparations and gross dissections may be made or demonstrated in the laboratory, in conferences, and with projection apparatus; and such special aspects of reproduction and embryology as the evolution of sex, the function of fertilization, human embryology, etc., may command special attention.

LABORATORY PROBLEMS IN MORPHOLOGY

There is practically no limit to the list of plant and animal species whose structures can be examined in the laboratory, and the following represents only a selection, albeit a more than suffi-

cient amount of material for use in the unified biology course. The page references are to the detailed outlines in the author's *Workbook in Biology*.

Demonstration of Organs and Tissues (p. 57)
Grasshopper: External Structure (p. 59)
Grasshopper: Internal Structure (p. 63)
Cockroach: Internal Structure (p. 67)
Crayfish: External Structure
Crayfish: Internal Structure
Earthworm: External Structure (p. 69)
Earthworm: Internal Structure (p. 71)
Frog: External Structure (p. 73)
Frog: Internal Structure (p. 77)
Comparison of Vertebrate and Invertebrate Structures (p. 83)
Leaf Structure (p. 87)
Vascular Bundles (p. 91)
Stem Structure (p. 95)
Root Structure (p. 101)
The Growth of Bulbs
Structure of a Typical Flower (p. 105)
Spring Flowers (p. 277)
Flower Record (p. 109)
Seed Structure
Osmosis (p. 117)
Chick Embryos (p. 121)
Embryology of a Dicotyledon (p. 125)
Embryology of a Monocotyledon (p. 127)
Cell Structure
Alternation of Generations (p. 7)

FIELD PROBLEMS IN MORPHOLOGY

Grasshopper: External Structure (p. 59)
Earthworm: External Structure (p. 69)
Frog: External Structure (p. 73)
Leaf Structure (p. 87)
Stem Structure (p. 95)

Root Structure (p. 101)
Structure of a Typical Flower (p. 105)
Flower Record (p. 109)
Plant Structures Used as Foods (p. 115)

SPECIAL TEACHING PROBLEMS IN MORPHOLOGY

1. **Principles in morphology.** It is difficult to find a basis for unifying the plant and animal material in morphology—more so than in any other unit. Plant and animal structures are so unlike in detail that it is to some extent understandable that the morphologists remain sceptical of the possibility of working out a unified biology course.

Morphologically plants and animals are similar in having an organ-tissue-cell plan of structure, in the essentials of sexual reproduction, and in their development from single cells (usually from fertilized eggs) which give rise to the adult structures through a series of gradual processes in development. The similarities of plants and animals may well be emphasized by the presentation of these principles. In a biology course the principles should be emphasized, while the detailed structures of particular plants and animals are given less attention than is usual in botany and zoology courses.

2. **Student interest in morphology.** Just as there are mechanically-minded persons who delight in constructing things or tearing machinery to pieces, there are some students who find dissection unusually interesting. Nevertheless there are many beginners who are to some extent offended by animal dissections and to a great extent bored by the descriptive details and ungainly vocabulary which characterize most morphology as it is taught. Therefore, in both high school and in college classes, details and vocabularies should be reduced to a minimum, while emphasis is placed on principles and on a general understanding of the relations of structures to the processes served. Advanced courses in college are so often loaded with morphologic details that a semester's study may not give the upper classman the principles which the freshman can be given in an elementary biology

course. Consider, for instance, the thousands of students who have memorized the pictures of chick or pig embryos, and know the details of much organogeny, without ever grasping the significance of gradual development as the foundation principle of modern embryology.

But although we have long offered this objection to the excessive use of morphology, we have never proposed that all of it should be dropped from the elementary course. This is the extreme to which some educators and the latest texts have suddenly gone. There should be a happy mean between the excessive morphology of a few decades ago, and no morphology at all. The science does provide the foundation for an understanding of some of the other biologic sciences, and even a beginner should have the picture of a definitely shaped machine which is back of the processes which he observes.

3. **Offensive animal dissections.** The older teacher may forget or ignore the shock with which beginning students first look into an animal dissection. Most college zoologists will stoutly deny that the students are offended, but the students are likely to report that the first vertebrate dissections nearly make them leave the course. Others will admit that they have never taken any biology because they are repelled by "a stinking cat course."

It is recommended that the first dissection, especially in the high school, be made by the teacher as a demonstration, that it avoid as far as possible any show of red blood, and that it utilize some animal which commonly enters the kitchen as food. The hen probably comes as near as any species to filling this bill..

It is recommended that no red-blooded animals be included in the program for individual student dissection.

Continual insistence on cleanliness in all dissections, constant washing of specimens being dissected, and prompt emptying of dirty water, dissecting pans, waste containers, and sinks, will do much to counteract any squeamishness among the students.

4. **Choice of dissection material.** Because of the availability of endless material, it is a common error to include too many dissections in the biology course. The unit should be kept

in its place as one of at least seven which are to be surveyed. For animal dissections, the following choice is very commonly used in both high school and college. A shorter list might include only the grasshopper and frog, or even be centered on the grasshopper alone.

Grasshopper. A good beginning because it is specialized enough to show numerous organ systems, because it does not involve the dissection problems presented by a vertebrate, and because it is large enough for easy handling.

Cockroach. As good as the grasshopper except for its smaller size. A good second dissection for comparison with the grasshopper.

Crayfish (or lobster). As good as the insect for the first dissection, except that it is unpleasantly smelly. Usually studied in such detail that classes often tire of the work.

Earthworm. Often used for the first dissection, but the segmental arrangement of the organs is too far removed from the structure of higher animals. The form of the animal is also more objectionable to some beginners

Frog. Perhaps the cleanest vertebrate ordinarily available, with its bones presenting a minimum of difficulty in dissection. Fundamental differences from human structure should be pointed out.

Material used to illustrate *plant morphology* is sometimes chosen from each of the main phyla and classes: a flowering plant, a fern, a fruiting moss, a fungus, an alga. The species used may be almost any of the things that are available in the region at the particular season. There is little point (unless in some city schools) in spending effort and money in procuring particular species from greenhouses. A series like the above may have been used in the unit on taxonomy.

A plant sequence which is preferred for the biology course, and one preferred by many teachers for the more special botany course, draws on a variety of vascular plant materials to illustrate the structures of leaves, stems, roots, flowers, seeds, and fruits.

5. **Logical versus pedagogical sequence.** It is an old principle to proceed from the familiar to the less well known. In morphology this means proceeding from whole plants or animals

to organs, then to tissues, then to cells. The reverse order might be more logical, but it is certainly wrong pedagogically. To start with work on cells involves the difficulties of microscopic work and a tall use of the student's imagination; and these are sources of difficulty both in the high school and in the college.

Similarly, dissections which follow the systematic sequence of protozoa to vertebrate, alga to seed plant, are a great cause of grief to beginners. It is pedagogically sounder to begin with the seed plants, with which everyone has had a certain amount of experience; and indeed the plant morphology in a biology course might well be confined to the structures of seed plants. With animals, the insects and vertebrates are the familiar forms, and with the internal structures of these, beginning students may already have some familiarity because of their study of human structure. The animal sequence indicated on the preceding page is, therefore, better than a strictly systematic sequence.

6. **Dissection technique.** Beginning teachers often have a mistaken idea that a special technique of dissection is necessary for each species studied. Hence the common reliance on manuals that outline the precise procedure for the form being used in the laboratory. On the other hand, any animal may be dissected by noting the following rules, and these rules may also apply to the much simpler dissection of gross plant structures:

Use fine-pointed forceps and dissecting needles, and occasionally fine-pointed dissecting scissors (85 cents for such a set of three instruments). Never remove any structure until you are sure you know what it is, that you know all you wish to learn about it, and that it must be removed in order to see what is beneath. Use forceps and needles for most of the work, scraping or teasing (gently tearing) tissues to examine or remove them; do not cut with scissors (or other instruments) unless it is absolutely necessary.

7. **Reproduction.** The study of reproductive morphology should not be dissociated from reproductive physiology. Even though the resulting combination may be more concerned with function, its presentation at this point in the unit on morphology

is demanded as a preliminary for the subsequent consideration of embryology (the morphology of the developing individual).

Twenty years ago it still seemed a matter for debate whether the subject of reproduction should be presented in a biology course offered beginning high school students. Even today almost half of the secondary schools offer no sex instruction. There is so much in biology—plant and animal reproductive structures, the function of the flower, the origin of the seed and the animal egg, embryology, the entire story of heredity, and much of animal behavior—that is dependent on an understanding of the origin of the new individual in the union of two parental germ cells, that it is difficult to understand how any fair presentation of the science can avoid the fundamentals of sex and reproduction.

It, indeed, seems that such material should be part of the early education in the home, and an increasing amount of it will probably go there within the next few years. The present generation of young parents is generally ready to admit that there are many social problems which cannot be complicated and some that might even be helped by a wider dissemination of knowledge of sex; and today there are few communities in which any serious objection would be raised to a presentation of the strictly biologic phenomena. Where objections are raised it is usually because the high school teacher has gone beyond the biology into the social and moral problems involved; and social and moral evaluations may constitute something very different from scientific data.

. The following would seem to be the material on sex which the beginning high school student needs in a course in biology:

New individuals originate only as the offspring of other living individuals.

Asexual division is the simplest means of reproduction. It is found in the simplest organisms.

Sexual reproduction, for some unknown reason, is the means employed in most higher plants and animals.

In sexual reproduction each species exists in two forms, male

and female, each of which produces different types of special reproductive cells, the sperm and eggs (*e.g.* in flower pollination).

A sperm and an egg, uniting, may produce a fertilized egg cell. A fertilized egg differs from an unfertilized egg in its ability to grow into a new individual.

Among higher animals, reproductive instincts guide the behavior of the adults so that eggs and sperm are brought together. The mating of the salmon, toad, and honeybee, noting the internal fertilization found among the higher forms, provides an illustrative series.

The developing eggs are protected by jelly or hard coverings (*e.g.* fish, amphibia, reptiles, birds); but among the mammals they are retained in the body of the mother where they are protected and fed until the young are well developed. Thus the young of mammals are born alive.

The above outline largely follows the presentation recommended by various other teachers and by the material in the author's *New Introduction to Biology*. It is to be noted that that chapter was put into print only after it had been used with some 13,000 boys and girls of high school age, during which time it was being continually modified on the basis of criticisms offered by educators with special experience in sex education. This material for the beginning adolescent represents, therefore, the choice of a group of experienced people.

There are, however, some teachers who object to the presentation of this much material on sex to a beginning class in the high school. In some cases the difficulty appears to lie in the emotional reactions of the teachers themselves. Reproduction should be made, as it is, as much a part of the everyday biology of plants and animals as digestion or respiration or any other biologic function. If the teacher will accept it as such, omitting any reference to the social and moral problems involved, and above all avoiding any emotional display in the presentation of the material, the reactions of the students should present no difficulties.

On the other hand, there are some teachers who would go

farther than this outline and consider the personal and social aspects of sex in the course in biology. But the wisdom of this is to be questioned. The scientific backgrounds, the psychologic problems, the social problems, and the force of the mores involved are very complex factors to weigh. It is to be questioned whether the average teacher of biology is qualified to make a fair balance of such diverse items. Under the guise of science we too often have sex instruction which is a curious even if a well-intentioned mixture of superstition, religious evaluations, and a mere perpetuation of social custom. The difficulties involved in translating scientific data into social action may be realized by comparing the older type of material intended for pedagogical use (*e.g.* Bigelow 1916 and 1936, Meagher 1936) with more recent educational literature (Rice 1933), and with objective studies in this field (Davis 1929, Hamilton 1929, Taylor 1934, Dickinson and Beam 1932 and 1934).

Certainly the presentation of the biology of sex should not be weighed down with an emphasis on the abnormal, an error into which physicians are likely to fall if they are called in to give instruction, and an approach too often used by educators. From a scientific standpoint, the consideration of venereal diseases, for instance, belongs to that part of physiology concerned with the other germ diseases; and there, along with the treatment of typhoid, smallpox, etc., they should be presented as contagious diseases transmitted through sexual contacts and affecting the reproductive as well as many other organs. And the youth's problems of masturbation and sublimation are so largely psychologic and social that a great deal more damage than good may be accomplished by any consideration which is not based on the most modern studies of the subject (Davis, Taylor, Dickinson and Beam, Hamilton, cited above).

8. **Laboratory in embryology.** The elementary laboratory in morphology is usually confined to plant and animal dissections. A special word should be said for the problems, listed above, involving a study of chick embryos and plant seedlings. Some teachers feel that work with chick embryos is too difficult for high school use. That this is a mistaken opinion is evidenced

by the fact that there are, here and there, a number of teachers who find it a thoroughly practical and outstandingly effective source of study for ninth and tenth grade students. It has even found effective use in some eighth grade classes in general science.

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CHAPTER XX

TEACHING PROBLEMS IN PHYSIOLOGY

PHYSIOLOGY IS THE SCIENCE WHICH occupies the leading place in biologic research today. Dependent in no small degree on the morphology with whose functioning the physiologist deals, it was the first of the other biologic sciences to be added to the purely morphologic course in botany and zoology, and one science that is always included in general biology courses.

OBJECTIVES

1. The science is attractive to young students because it deals with the workings of plant and animal machines. Physiology and behavior, both of them concerned with what organisms *do,* thus contribute to a live biology.

2. Direct applications of physiology are made in hygiene, community sanitation, and dietetics. With some understanding of the fundamentals of physiology the everyday citizen is much better equipped to make specific applications in these other directions.

3. Physiology clearly shows the unity of plant and animal processes. It was in this field that a real unification of botany and zoology was first made. The beginning student will find it interesting to see how similar all organisms are in their fundamental physiology.

SUGGESTED CONTENT

The following outline provides a basis for unifying all physiologic activities of both plants and animals. That it is not too difficult for beginning students is abundantly proved by the extensive test to which the program has already been submitted by some thousands of high school teachers. For the colleges, the same material may be developed with a more detailed consideration of many points.

PHYSIOLOGY

Protoplasm, the basis of all life processes
- Composition
  - A mixture of compounds of C, H, O, and N
  - With additional minerals
  - In water
- Qualities
  - Definite form and structure
  - Growth
  - Reproduction
  - Sensitivity
  - Life

Building Foods and Protoplasm (Anabolism)
1. Materials used
   - Carbohydrates, by photosynthesis
   - Fats, obtained directly or by transformation of carbohydrates
   - Proteins, formed through nitrogen fixation and nitrification
   - Minerals
2. Digestion
3. Assimilation
   - Significance of vitamins

Using Foods and Protoplasm (Katabolism)
- Energy released by:
  - Respiration
  - Fermentation
  - Waste
  - Decay

- Energy released as
  - Heat
  - Motion
  - Electricity
  - Nervous energy
  - Light
- Secretions produced
- Enzymes
- Hormones

Hygiene as Applied Physiology

- Food hygiene
- Poisons and drugs
- Respiration and excretion
- Exercise and rest
- Disease
  - Causes
    - Organic
    - Germ
      - Bacterial
      - Protozoan
      - Worm
  - Distribution by:
    - Air
    - Direct contact
    - Insects
      - As mechanical carriers
      - As necessary mechanical carriers
  - Immunity to disease

LABORATORY PROBLEMS IN PHYSIOLOGY

The page references are to the detailed outlines in the author's Workbook in Biology.

Sugars as Foods (p. 131)
Starches as Foods (p. 133)
Fats as Foods (p. 135)
Proteins as Foods (p. 137)
Food Elements in Milk (p. 139)
Menus (p. 143)

Vertebrate Respiration (p. 147)
Grasshopper Respiration (p. 151)
Products of Animal Respiration (p. 153)
A Product of Plant Respiration (p. 155)
The Withering of Leaves
Pulse Rate (p. 157)
Circulation of Blood (p. 159)
Seeds, Germination, Respiration, etc.
Capillarity in Plants
Regeneration
Respiration and Circulation in the Frog
Detection of Food Adulterants

FIELD PROBLEMS IN PHYSIOLOGY

Some Physiologic Processes (p. 129)
Classification of Market Foods (p. 141)
Commercial Producers of Foods (p. 145)
Fly Breeding Places (p. 161)
Mosquito Breeding Places (p. 163)
Restaurant Biology
Community Sanitation
Trip to Waterworks

SPECIAL TEACHING PROBLEMS

1. **The unity in physiologic processes.** As we have already pointed out (Chapter VI), it has been a chief difficulty in the teaching of physiology to show the relations between the numerous special activities of plants and of animals (digestion, reflexes, muscular activities, photosynthesis, hormones, respiration, blood circulation, sap circulation, etc.) and especially to show the similarities of the processes in plants and in animals. On the other hand, the arrangement of the material outlined on pages 208 and 209 puts all of these processes in one continuous chain, starting with the storage of the sun's energy in the building of foods and protoplasm, and concluding with the release of energy in the destruction of those same materials.

2. **Position in the sequence of units.** Although any special consideration of physiology would depend on morphology, such general physiology as is here outlined for the introductory course is neither pre-requisite to nor dependent on any other unit. But there is a certain amount of chemistry involved in even the simplest consideration of foods and protoplasm. Even if the detailed chemistry of enzymes, hormone activities, etc., is touched very lightly, the unit is still difficult for beginners. While physiology is, therefore, logically a good introduction to a biology course, its difficulty requires that it be placed later in the semester. Most, but not all, of the laboratory and fieldwork in the unit can be conducted in the winter, although a season when some green plant material and grasshoppers are alive would offer further opportunities for this work.

3. **Over-emphasis on physiology.** Important as physiology may be, it must not be forgotten that it is only one of six or seven biologic sciences that should be surveyed in a beginning course. Some of the newer texts in biology, both in the high school and college fields, devote a half or even seven-eighths of their space to physiology. Courses so shaped are in reality introductions to physiology, and not to biology as a whole. It is natural enough that the physiologists should consider their science as basic and as significant as the morphologists considered their subject in the day of the exclusively morphologic course. But if biology is to be presented in a survey course, there must not be an over-emphasis on any single sub-science.

4. **Too much chemistry.** It is a common error to include too much chemistry in this unit, thereby increasing the difficulties for beginners. Experiments that are often used are designed to show the chemical qualities of carbon, hydrogen, oxygen, and nitrogen, the analyses of foods and products of destructive metabolism, etc. Such work may involve an extensive use of apparatus, and the unit becomes a major item of expense in the year's program. The student loses sight of biologic principles in the complexities of laboratory technique. While advanced courses in physiology will of necessity involve a great deal of chemistry,

it is disastrous if the introductory course strays too far from the biology of living plants and animals.

5. **Emphasis on applied sciences.** This question is considered in Chapter IX on *Pure Versus Applied Sciences* (*q.v.*). The issue has been a real one in the teaching of elementary biology. There have been some who have built the course entirely out of problems in human hygiene and community sanitation, and the traditional attitude of the research scientist has led him to the other extreme of ignoring all practical matters here as well as in other units. The reasonable solution of the question, as we have already proposed, seems to lie in building the unit about general principles, while making enough of the applications to win the student's interest, to provide him with specific tools for meeting some of his everyday problems, and to illustrate how the principles may be applied to the new situations which he may meet later in life. While some hygiene may, therefore, be included in this unit, any detailed consideration of such an applied science needs more time than can be given it in a balanced biology course.

Where and how hygiene should be taught is one of the problems still to be solved by curriculum makers. The subject needs solid bases in physiologic science, rather than in the morphology usually employed; and it should be taught by teachers with some grounding in the biologic sciences. How much formal work in hygiene should be presented in the grade school, in the high school, and in the college is a matter that is certainly not yet established. There is a great deal to be said for teaching most of it in the very lowest grades, at a time when the child is forming his everyday habits. But wherever the special course is put, hygiene cannot occupy too much space in general biology. It is the chief end of our teaching to introduce boys and girls to the plants and animals of this world—to awaken their interest in the variety of life all about them—not merely in the health and disease of the human animal.

6. **Scientific interpretations of disease.** If any aspect of hygiene is to be included in the biology course, it may well be the question of the nature and control of disease. This is one

subject which can be based on broad principles well established by the most careful sort of scientific work. The observations on disease germs which can be seen under the microscope, the experimental demonstration of their relation to disease, and the modern technique for developing immunity represent sound contributions in modern science. To relegate germs and diseases to the realm of imagination, as certain people would have them, is to deny an ability to observe matter. With that attitude, science can never agree.

There are parts of the United States where religious and medical cults, by preventing the passage of vaccination laws, opposing the teaching of the science of disease, and forbidding the use of animals for experiments looking to the control of disease, have succeeded in raising the death rates for some of the contagious diseases to points approaching the death rates in backward portions of China. Sometimes the teacher will have to acquiesce to local objections; but wherever such objections are not supported by law, or enforced by the general sentiment of a community, it would seem a special obligation of the biology teacher to defend not only the specific data of this science, but the validity of the scientific method as a means of acquiring knowledge about disease. With elementary classes, it may be wise to present the biologic data without reference to the attitudes of those who object to the scientific investigation of disease.

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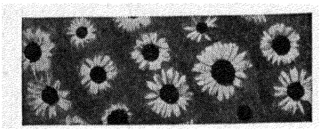
CHAPTER XXI

TEACHING PROBLEMS IN GENETICS



SINCE THE BEGINNING OF THE CENTURY there has been a great advance in the scientific understanding of heredity and evolution. Genetics is now such a significant part of established knowledge that no course has given a fair introduction to biology until it has summarized the principles of this new science.

OBJECTIVES

1. One's interest in the living world is considerably increased if he understands something of the reasons for the similarities and differences which he sees everywhere about him, among individuals of the same and of different species.

2. Genetics may contribute to the teaching of the scientific method. It will mean much for the health and happiness of the individual and of human society if average men and women learn to think of problems of heredity in terms of genes. Such age-old questions as the relative importance of heredity and environment must be settled by a consideration of scientific data instead of a dependence on superstition and an appeal to emotional fanaticism. The tragedy in any popular rejection of evolutionary ideas lies, not in the failure to acknowledge the facts, but in the failure to understand that scientific methods are the only adequate bases for determining the questions involved. In this study of genetics, the beginner may acquire a sound

approach to problems that are too commonly misinterpreted by everyday men and women.

SUGGESTED CONTENT

For high school use, the following organization of material has proved a practical presentation of genetics.

Genetics

Heredity
- Physical basis
  - Chromosomes and genes
  - History of genes in maturing germ cells
  - History of genes in fertilization
- Behavior of characters in heredity
  - Unit characters
  - Pure-line heredity
  - Heredity of contrasting characters
    - Genic history
    - Dominance
    - 3-to-1 ratio
  - Ratios are averages
- Characters inherited
  - Physical, physiologic, and psychologic
  - Applications to the human (including some eugenics)
- Modification of hereditary characters by environment

Evolution
- Bases of individual variation
  - Environment modifying inherited characters
    - Not heritable (Lamarckianism)
  - Hybridization
    - Basis of individual differences between brothers and sisters
    - Basis of new kinds of domesticated plants and animals
    - Basis of new species in nature
  - Mutation
    - Occurrence among domesticated plants and animals
    - Cause of mutation

Origin of species
  Origin as hybrid or mutant individuals
    Isolation of new types
    Giving rise to interbreeding populations
  Adaptation: a directive force in evolution?
Course of past evolution
  Evidenced by similarities in structures
  Evidenced by similarities in physiology
  Evidenced by vestiges
  Evidenced by embryonic recapitulation
  Evidenced by fossils

For colleges the above organization may still hold, with some consideration of such advanced subjects as the following:

1. Heredity
   Crossing two pairs of contrasting characters
   Multiple factors in heredity
   Data on human heredity
   More extensive treatment of eugenics
2. Evolution
   More extensive treatment of field data on evolution
   More critical analysis of Lamarckianism
   More critical evaluation of Darwinism (adaptations, and the struggle for existence)
   Orthogenesis
   Human evolution

LABORATORY PROBLEMS IN GENETICS

The page references are to the detailed outlines in the author's Workbook in Biology.

The 3-to-1 Ratio in Corn (p. 165)
Why It Is a 3-to-1 Ratio (p. 167)
Individual Variation in Beans (p. 171)
Other Cases of Variation (p. 173)
New Breeds (p. 175)

Adaptations in Insect Legs (p. 177)
Protective Colors of Vertebrates (p. 183)
Bird Adaptations for Feeding (p. 205)
Seed Adaptations for Overwintering

FIELD PROBLEMS IN GENETICS

Good Breeds and Bad Breeds (p. 169)
Individual Variation (p. 173)
New Breeds (p. 175)
Some Plant Adaptations (p. 181)
Fossils (especially in limestone areas)
Modern Iris
Cave Faunas
Varieties of Garden Plants

SPECIAL TEACHING PROBLEMS

1. **Difficulties of the subject.** There is reason for believing that student difficulties in genetics are due in no small part to the poor preparation of the older teachers in this relatively new field. When the elements of the subject are mastered by the teacher, the student should find genetics not more difficult than morphology or physiology.

There are certain mathematic aspects to Mendelism which show the precision of hereditary processes; but these very mathematics appall certain students, and involved problems in genetics should be kept at a minimum in elementary classes.

Some of the difficulty which beginners have here is due to the use of Mendel's own work as a historical introduction to the subject. The Mendelian experiments do not represent the simplest cases in heredity (*e.g.* a red and white cross giving rise to pink-flowered peas involves factors which Mendel was unable to interpret). Mendel knew the behavior only of the characters, and nothing of the genic bases for heredity. It is poor pedagogy to recapitulate historic errors in present-day teaching. It is better to begin with an account of the gene whose behavior can very simply be connected with the behavior of characters in heredity.

A specific source of difficulty to beginners is the detailed account of mitosis with which most university texts, some of the high school texts, and at least one grade school (!) hygiene text begins the story of maturation. The thing is quite academic for students who have not had considerable microscope experience, and a perfectly clear elementary account of gene behavior in maturing germ cells can be given without mentioning mitosis. College teachers should try the procedure with a class or two before they offer the traditional excuse that this is one of the fundamentals on which to base an understanding of heredity [in research? or in elementary teaching?].

2. **Galton's laws and Mendelian ratios.** An additional source of confusion to students is sometimes introduced by teachers who have received their training in certain agricultural schools. These teachers present Galton's ratios in inheritance, either together with or as substitutes for the Mendelian ratios. While Galton's laws apply to averages *for the entire mass of characters* in any hereditary line, they give no analysis of unit characters in particular individuals. Their presentation in combination with, or as a substitute for, Mendelian ratios can do nothing but confuse beginners.

3. **Possibilities in laboratory and fieldwork.** It is commonly objected that it is not feasible to do laboratory or fieldwork with beginning students in genetics. This objection may apply to some of the fruit-fly and plant breeding experiments which are used by advanced classes; but the lists given above include a goodly number of both laboratory and field periods, in both heredity and in evolution. They prove among the most interesting in the whole field of biology, and are quite effective in teaching biologic principles and scientific method. If one has stayed with the traditional laboratory routine of morphologic dissections and physiologic experiments, genetics might be recommended as the best of the other sciences with which to broaden the older program.

4. **Relative importance of heredity and environment.** There are some science teachers who carelessly invite their students to determine whether heredity *or* environment is more

important to human affairs. If these questions are to be raised —as certainly they should be among the boys and girls who will be the adults of the near future—it should be made clear that *neither* heredity nor environment is more important—that each serves in a different way. Heredity provides the equipment, but the environment decides how much of that equipment may be used. Heredity sets the upper limits beyond which environment can accomplish nothing; the environment may set a lower limit, above which the best of heredity is useless. The future of society depends on the quality of its heredity and on an environment capable of bringing out the maximum of these hereditary capacities.

5. **Eugenics.** Eugenics is, admittedly, one of those composites which are known as applied sciences. Whether it is soundly enough established to be included in any science course, and whether it should be discussed with high school or even college students, are questions that have caused some concern to biology teachers. Only recently have there been indications that eugenics is going to find a permanent place both in high school and college teaching. Events of the last decade have made the younger generation wonder how far genetic factors account for the dependence of a third of the population on the other two-thirds, even in times of prosperity. It is one of the most hopeful signs for the future that young people are becoming interested in problems of human breeding. The careful scientist sometimes replies that very little is in actuality known about human heredity; but this seems no good reason for withholding scientific support from the application of what is known. To some of us it appears better to have eugenics kept closely connected with its chief scientific basis, genetics, than that it should be handled by propagandists in some other field.

The objection is raised by some of the older high school teachers that any discussion of human heredity may make young students morose, and be a cause of needless worry to youth who are not yet facing the issue of marriage. But ideas of eugenics, like most sex instruction, come too late if they are reserved for married adults. There is a growing belief that eugenic ideas

should be given boys and girls at least as early as their first interests in companions of the opposite sex. This means that the instruction must begin in the early high school years. Since very few of the high school students ever get into college classes in eugenics, the instruction in the high schools must go far enough to hold over until the youth contemplates actual marriage.

There is some organized opposition to certain aspects of the eugenics program, and its introduction into the high school, and even into the colleges, must depend strictly on scientific foundations. In working out his policies in eugenic instruction, each teacher must proceed slowly until experience has shown just how much can be effectively offered adolescent boys and girls. Anticipating what is hardly yet in the elementary texts, the following may be submitted as the first materials from which to choose:

The heredity of a fair list of morphologic, physiologic, and psychologic characters in man is now certainly established, and a fair understanding of their course in heredity is now to be had.

There is every reason for believing that the effects of heredity and environment are as significant for man as for the other organisms which have been studied.

More than 2 per cent of our population is hopelessly dependent because of mental defects that are known to be hereditary. There is no record to show that this group ever produces any individuals that are socially valuable.

The percentage of hereditary defectives is constantly increasing, because such defects are spread by apparently normal as well as by abnormal individuals. The normal individuals from hereditarily defective families may carry the defects in recessive genes.

We face an indefinite increase in the number of such defectives unless we can in some manner prevent reproduction in these individuals. Already the care of these defectives costs more than the education of all the college students in the country.

The complete isolation of all such defectives (which no state has yet been able to afford), or their sterilization, are the only

two methods available for controlling the spread of hereditary defects.

While it would be very difficult to decide which was the socially more important and which the socially least important half of any population, there would be little difficulty in selecting the 10 per cent which is the greatest drain on the advancement of our social institutions. The limitation of reproduction among this 10 per cent may be necessary before we can expect any decrease in the number of helpless dependents. How the control of the group may be accomplished is a matter of debate.

While the mass of the socially worth-while individuals, and even some leaders have come from the middle classes, the data abundantly prove that most leaders have come from the group which is the best equipped in hereditary capacity and environmental training.

Young people who are hereditarily sound and environmentally privileged may contribute to the quality of society by planning to have as many or more children than the average for the whole population. With less than three children to a family, the hereditary line which they represent will soon become extinct, and society deprived of the qualities carried in that line.

6. **Evolution.** It is difficult to understand how any adequate presentation of biologic principles can be made without reference to evolutionary concepts. The whole scheme of taxonomic classification, and one's interpretations in comparative morphology, physiology, and behavior, are influenced by the data on evolution. There is no part of modern biology which has not been affected by this idea; and even though there is not complete agreement as to the particular factors that have been involved in evolution, there are no biologists who are not agreed that evolution has occurred.

While the biology course will, then, of necessity include evolutionary ideas and material, the teacher of beginners, especially in the high school, should confine himself to thoroughly established data, and omit references to evolutionary items which are not required for an understanding of biologic essentials.

Specifically, the data considered may be such individual variation as every man can see in the human, in plants, and in the animals about him, and the records from domesticated and laboratory organisms. No one, unless he is ready to insist that black is white, is likely to object to such material. Such everyday facts are well known to the farmer who grows improved breeds of cattle and grains and fruits which were not in existence a half century ago. The man who gardens for recreation is aware of the endless list of new kinds of flowers, shrubs, and trees which scientific horticulture has to offer him. The housewife who deals in a modern fruit and vegetable market cannot help but know that the old varieties have given way to new—to varieties which are astounding departures from the things that were available in grandmother's day. These everyday instances of variation and improvement, taken in connection with the abundant laboratory experiments on heredity, are, after all, the soundest bases for generalizations in evolution. The data from comparative anatomy, physiology, embryology, and even fossils are more circumstantial, and need not be pressed with elementary classes.

The evolution of man is, by some, conceived to involve special problems which lie outside of science. High school students are hardly qualified to evaluate all the data; and under the circumstances one is probably not justified in presenting bare conclusions on one side of the argument. In the high schools it would be a fair avoidance of prejudice to refuse to discuss human evolution. With college students, the situation is, of course, quite different.

It is to be noted that there are no state laws which seriously interfere with the presentation of strictly scientific data, in this or in any other field. There is good evidence that the public, practically everywhere, is ready to allow the presentation of established fact, although it may resent the use of the science to put across ideas that involve (even in part) another field of thought. The biology teacher who cannot present evolution without offending a community is probably indiscreet in the handling of the material.

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* Recommended as the best books for student use.

CHAPTER XXII

TEACHING PROBLEMS IN ECOLOGY

ECOLOGY IS THE SCIENCE WHICH IS concerned with the relationships of organisms and their external environment. Since it is a characteristic of protoplasm that it readily reacts to stimuli, the ecologist considers that the reacting organism in its environment is nearer reality than single plants and animals, or such parts of organisms as are brought into laboratories for examination.

The older natural history consisted in large part of ecology, with which were combined portions of what are now called taxonomy and behavior. The formal development of modern ecology is a thing of the last two decades.

OBJECTIVES

1. **Interesting students.** For average future citizens who will meet the living world under natural rather than under laboratory conditions, ecology and behavior will probably contribute more of interest than any of the other biologic sciences.

2. **Practical applications.** There is no science which contains as much applied biology as ecology. Here are the biologic bases of the problems involved in any search for food and clothing among the plants and animals of the world; the utilization of favorable environmental factors in the production of crops;

the protection of the crops and of man's own person from other plants and animals, and from the inorganic factors which interfere with their development. All economics (the relation of the human animal to its environment) have an ecologic basis. While the newness of the science of ecology and its still unorganized state make some research biologists hesitate to include very much in the introductory course, the outstandingly human interests and unlimited practical applications of the science bespeak a prominent place for it in both high school and college programs.

SUGGESTED CONTENT

For high school student use the following presentation of ecology gives a background of principles adequate for making many applications to specific situations. This outline might serve even in such special courses as agriculture to provide the bases on which the practical work is to be built.

Ecology

- Basic Principles
  - Reactiveness of protoplasm, the basis of ecologic relations
  - Types of relations
    - Inorganic: temperature, moisture, light, climate, etc.
    - Organic: sexual, threptic, symbiotic, predatory, parasitic, scavenger, etc.
    - Economic relations
    - Chains and webs of relationships
  - Balanced relations
  - Epidemics: upsets of balanced conditions
  - Control of ecologic relations
    - Artificial control of pests
      - Direct attack
      - Poisons
      - Repellants
      - Fumigants
    - Cultural control
    - Extermination
    - Biologic control

Special instances of ecologic relations
- Economic importance of forests
- Economic importance of insects
  - Reasons for dominance
  - As direct pests
  - As enemies of agriculture
  - As disease carriers
  - Beneficial insects
- Economic importance of birds
- Cross-pollination
- Galls and gall insects
- Relations of aquatic organisms and their environment
- Household pests
- *Etc.*

The college teacher may count on the student having some knowlege of some of the special cases of ecologic relations and prefer to emphasize and expand the work on ecologic principles.

LABORATORY PROBLEMS IN ECOLOGY

The page references are to the detailed outlines in the author's Workbook in Biology.

Effects of Freezing Temperatures (p. 191)
Composition of Soils (p. 195)
Water Evaporated from Leaves (p. 197)
Plants as Soil Covers (p. 199)
Forests as Water Controls (p. 201)
Bird Adaptations for Feeding (p. 205)
Plant Galls (p. 209)

FIELD PROBLEMS IN ECOLOGY

Typical Ecologic Relations (p. 185)
A Field Survey (p. 187)
Mid-winter Plants and Animals (p. 189)
Habitats (p. 193)
Composition of Soils (p. 195)

Forest Products (p. 203)
Plant Galls (p. 209)
Insect Enemies of Trees
Insect Enemies of Gardens
Insect Pests on the Farm
Principles of Forestry
Aquatic Organisms
Cross-pollination
Fly Breeding Places (p. 161)
Mosquito Breeding Places (p. 163)
Cave Faunas

SPECIAL TEACHING PROBLEMS IN ECOLOGY

1. **Principles versus applied biology.** Ecology and physiology are the two units in which the problem of a pure versus an applied science is most involved. For the general solution see the discussion in Chapter IX. There is a great deal of applied biology in a number of the high school texts, and the economic biologies are written mostly in this field, but there is almost no discussion of principles. It is important that the student understand that there are general principles involved, and that all the special cases are applications of the same principles. The teacher should relate each of the special cases with the principles.

2. **Laboratory program.** The laboratory work which has proved successful with beginning students in ecology is not enough to fill as many hours as are ordinarily allowed in the other units. This is one case where one might frankly omit much of the laboratory, emphasize the fieldwork, and give extra time to special projects, or to reports on the outside reading recommended in the reference lists below.

3. **Fieldwork.** There is no limit to the fieldwork which can be done in this unit, and it is unusual in being effective at every season of the year. The unit, consequently, may be placed anywhere in the program as far as seasonal factors are concerned. The fieldwork might well substitute for most of the regular laboratory hours. Inasmuch as almost everything that is noted out-of-doors has evident ecologic relations, there is a temptation to

make the field trips very general, utilizing everything that comes along. But if the work is to contribute specifically to the student's education, it is still imperative that each trip be confined to a particular topic which correlates with the textbook assignments and the subjects of the recitations.

4. **Special reports.** There is an abundance of special literature in ecology. There are a great many state and federal publications which are available even to the most poorly equipped school. (See the reference lists below.) The number of possible topics for reports is almost unlimited, and the teacher may readily devise a list from the literature that is available in the particular school.

SELECT REFERENCE LIST IN ECOLOGY

In High School Texts

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CHAPTER XXIII

TEACHING PROBLEMS IN BEHAVIOR

LIKE ECOLOGY, BEHAVIOR HAS RECENTLY grown from its natural history foundations into an organized science. There is in consequence not much of it included in most of the texts. But there is such a wealth of behavior material which is of interest to everyone that there is reason for its emphasis in the elementary course.

OBJECTIVES

1. As an aid to the interpretation of the interesting things in this world, there is no biologic science (unless it be taxonomy) which has more to contribute. What living things do, and why they do it, is of more interest to the average boy and girl than the structures of plants and animals. Because gross activities are more readily observable, and internal activities more difficult to observe and analyze, the beginner finds behavior more interesting than physiology. The research student may have to turn to the ultimate physiologic processes to find the roots of behavior; but the average boy will prefer to lie on his stomach and see what the ants are doing, crane his neck at the soaring hawk or buzzard, and note the apparently ingenious turn made by the vine in bringing itself into the sunlight. The bumblebee's nest, the snake-skin lining of the great-crest's home, the mouse's cunning, and the spider's skill, the bird's song, or other equally interesting things lie along the path of every boy and girl, man and woman.

If the biology teacher will take time to introduce the student to these things, here is a unit with which to capture the attention of the most difficult boy—a climax to the year's work which should make every student wish the course was not over.

2. A general study of this science may also provide a basis on which the student may make some interpretations of human behavior. This is a somewhat practical application of this field of biology.

SUGGESTED CONTENT

For high school classes, the following material is suggested:

BEHAVIOR

- Interpretations
  - Basis in reactiveness of protoplasm
    - Mechanical nature of response
    - Common basis in both plants and animals
    - Types of reactions
      - Reflexes
        - Positive and negative responses
        - Modifiability
        - Nervous basis in higher animals
      - Tropisms
        - In both plants and animals
        - Basis in reflexes
        - Modifiability
        - Kinds of tropisms
      - Instincts
        - As chains of reflexes and tropisms
        - Mechanical nature
        - Heritable basis
        - Adaptive nature
  - Basis in modifiability of protoplasm
    - Memory
      - In non-living things, in plants, in animals
      - High development in insects and higher vertebrates
    - Reasoning
      - Basis in memory
      - Development in highest insects and highest mammals

Special studies (descriptive for each group, with some attempt to make interpretations in the light of the above analysis), *e.g.,* social wasps, bumblebees, honeybees, ants, termites, scavenger beetles, parasitic plants and animals, protozoa, earthworms, birds, mammals, human

In college courses it may be preferable to emphasize the interpretive aspects of behavior, leaving the more detailed discussion of the behavior of particular forms for the advanced courses in entomology, ornithology, etc.

LABORATORY PROBLEMS IN BEHAVIOR

The page references are to the detailed outlines in the author's Workbook in Biology.

The Sense of Touch (p. 211)
The Temperature Sense (p. 215)
Taste and Smell (p. 219)
Mechanical Reactions of Plants (p. 223)
Tropisms in Fruit Flies (p. 229)
Tropisms in Blow Flies (p. 231)
Tropisms in Earthworms (p. 233)
Leaf Mosaics (p. 235)
Instinctive Behavior of Earthworms (p. 239)
Instincts in Domesticated Animals (p. 241)
Ant Endurance Under Water (p. 249)
Ants and Water (p. 251)
Parasites (p. 253)

FIELD PROBLEMS IN BEHAVIOR

Plant Sleep Movements (p. 225)
Leaf Mosaics (p. 235)
Instincts in Domesticated Animals (p. 241)
Experiments with Ants (p. 243)
Ant Nests (p. 245)
Bird Behavior (p. 255)
Bird Nests (p. 261)

Bird Migration Record (p. 265)
Insect Behavior in Cross-pollination
Insect Color Preferences
Examination of Social Wasp and Bumblebee Nests
Observation of Solitary Wasp Behavior
Frog and Toad Mating Behavior
Spider Behavior

SPECIAL TEACHING PROBLEMS IN BEHAVIOR

1. **Persuading teachers to include the unit in the program.** Most of the observations which the average boy or girl, left to his own devices, will make on plants and animals will lie in the field of behavior. The only possible explanation of the omission of this material from most elementary teaching in the last thirty years is its neglect in the colleges in which the teachers are trained. The college situation is the result of the long period of specialization in morphology, and the consequent removal of biology from living contacts in the field. To repeat what has already been urged, there is no unit which will arouse more interest than this, if the teacher will venture into its teaching. Given the available field material, behavior is the one unit which may be considered the most important in a grade school nature study or a high school biology course.

2. **Live laboratory material.** But it is so much easier to lift a jar of preserved specimens off a shelf! And it does in truth require previous planning and time to prepare live laboratory material. However, here is one unit in which practically nothing can be done in the laboratory or field without live material. From this comes the value of the unit when properly taught—and hence, also, another reason for the hesitancy of many teachers to undertake laboratory or fieldwork in the unit. It is quite true that for some city schools the available live material is so scant that the teaching may have to be based on textbook and reference readings; but for most other schools a sufficient share of the laboratory and fieldwork listed above should prove perfectly feasible.

In the secondary schools the help of the students must be enlisted to secure the live earthworms, ants, or other material needed for the laboratory, and to care for them so they will stay alive and normal until the time for their use.

3. **Fieldwork in behavior.** Field trips are such an essential part of the study of behavior that it is imperative that the unit be placed in the program at a season when there is an abundance of live plant, active insect, and bird material for observation. But insects are too small for convenient demonstration to a large class in the field; and live insects and birds are so readily disturbed from their normal behavior that a large class has little chance of getting near them for prolonged observation. In much of the fieldwork it is, therefore, necessary to split the class into groups of four to six students, each of which might be under a capable student leader. The spirit of contest introduced between these groups, even if it enters into nothing more than a comparison of the reports rendered at the end of the hour, will ordinarily guarantee their continued attention to the subject matter.

4. **Observations must depend on undisturbed behavior.** Most amateur observers are inclined to push a finger into the field of observations in order to speed up the activities of the insect, worm, or other organism. But normal behavior can be observed only if the creature is undisturbed. If an experiment calls for the control of the animal's activities, care should be exercised to modify nothing except the experimental factors being introduced. For this reason, observations in behavior demand considerable time. The student may then come to realize what patient work it has taken to accumulate the information that is now available on the behavior of insects, birds, and other animals.

5. **Is behavior biology, or zoology?** One occasionally hears an objection to the inclusion of more animal than plant material in the study of this unit. As though the biologic nature of a phenomenon were to be measured by the extent to which it concerns both plants and animals! The protoplasmic bases of behavior are the same in both plants and animals; but it so happens that, due chiefly to the greater motility of animals, behavior

has become more complex there than among plants. Instincts and reason, limited to animals, belong in the biology course because they are the end developments of the basic behavior phenomena which are common to both plants and animals.

6. **Mechanistic interpretations.** There may be students and an occasional citizen who will object to the reduction of so many animal activities to mechanical terms of action and reaction. There are, ordinarily, no objections to similar interpretations of heart-beats, breathing, nervous impulses, and most other internal activities. The simple explanation may therefore be offered the inquiring student that the activities of the whole animal or of its external structures (which are the things studied in behavior), have the same bases as the activities of the internal organs which are studied in physiology.

As for the possibility that a highly developed brain may permit an animal to escape from its physico-chemical servitude, to exercise free-will, science has nothing to say. It knows that many of the activities of the brains of insects, of many vertebrates, and even of man, are as mechanically controlled as the simplest eye or heart or breathing reflex. But it also knows that the human brain is capable of many things which are not yet explainable in terms of physics and chemistry; and no careful scientist will predict that all mental phenomena will soon be reduced to such terms. As far as possible, avoid the issue with high school classes. If the question is raised, limit mechanistic interpretations to those aspects of behavior which are clearly so interpretable on the basis of the data.

7. **Watsonism.** It is unfortunate that the term *behavior* may be confused with the term *behaviorism*. *Behavior* is as old as natural history, but *behaviorism* is a type of psychology developed by Professor J. B. Watson, and better distinguished as *Watsonism*. Professor Watson's original investigations in bird behavior, and his first studies of human behavior, were noteworthy contributions which did much for the development of mechanistic attitudes in this field. That far, biologists will follow him. But the philosophy of Watsonism became pure agnosticism, denying the existence of instinct, of reason, and finally of con-

sciousness. The biology of behaviorism became a naïve Lamarckianism, with a complete denial of any significance in heredity. It is evident that the later philosophy has no foundation in the biologic sciences.

In an introductory study of behavior, biologists are most likely to conflict with Watsonian views on the subject of instincts. True Watsonians completely deny the existence of instincts. What they really mean is that the anthropomorphic interpretations of instinctive behavior given by the older naturalists and psychologists must be replaced by physico-chemical interpretations. With this viewpoint biologists are ready to agree. Watson analyzes the behavior commonly called instinctive as a succession of reflexes, and drops the word instinct for the chain as a whole. In doing so, he minimizes or ignores the connections that exist between the elements in the chain and, of course, denies the inherent bases of such connections. Biologists, on the other hand, see connections between the reflexes in a chain. Each reflex appears to be the stimulus which brings the next element in the chain into action. In order to emphasize the unity of the chain as a whole, they prefer to retain the word instinct, even though they no longer think of it as the mysterious, invariable, infallibly adaptive thing which the older workers considered it.

8. **Use of live animal material.** There are high school teachers, chiefly of the older generation, who object even to cutting the wings of flies for laboratory experiments in behavior. Few of the students find any objection to the use of live material; and the few squeamish individuals soon forget their doubts about earthworms and caterpillars if the instructor simply ignores their reactions and interests them in the objectives and procedure of the experiment. The student does not belong to a generation which needs sympathetic coddling of emotional prejudices. The only complaints that are likely to be raised against "vivisection" will come from some of the parents, or from the older teachers themselves. Criticism should be avoided by restricting all experiments in elementary classes to animals which are in no way allowed to suffer while they are kept alive. Of course, the cutting of a fly's wing inflicts no more pain than the cutting of one's

own hair or finger nails. But in handling vertebrates, care must be taken to keep the creatures under conditions matching the normal as nearly as is possible. Otherwise the animals may suffer; and, incidentally, they will exhibit normal behavior only if they are kept under normal conditions.

SELECT REFERENCE LIST: BEHAVIOR

The literature in this unit constitutes the most readable in biology. Therefore several of the special items from the following lists should be included among the first purchases made for the school library. If the students are once introduced to this material, many of them will find incentives for reading beyond the specified assignments and, in the years to come, may find many hours of pleasant recreation in further contacts with this unique literature.

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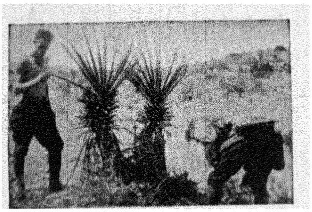
* Recommended as the best books for student use.

CHAPTER XXIV

THE TRAINING OF THE BIOLOGY TEACHER



IN THE LAST ANALYSIS, THE SUCCESS of any teaching program depends on the quality of the teachers. Even more important than questions of content, the choice of particular procedures for making tests, or the methods employed in the laboratory and field, are the qualifications of the teachers of biology. An expert teacher will succeed with a program, a syllabus, a text, and a technique which would spell failure for most of us. A poor teacher can follow the best outline, employing every approved pedagogical device, and still make a failure of the teaching. Whether the unified biology course can justify its position in the high school and the college will depend, in the long run, on whether we can find teachers who can effectively teach it.

A biology teacher may be expected to have the following qualifications:

1. A native interest in plants and animals out-of-doors.
2. An inborn ability as a teacher.
3. Some formal training in the biologic sciences.
4. Some knowledge of the essentials of formal pedagogy.

When a teacher is equipped with the first two of these items, he need not worry very much over the last two in the list. Although all of the teacher licensing schemes are based on the last two, obviously because of the difficulties involved in evalu-

ating the first two, it is on those things which are above formal training that the ultimate success of any teaching must depend.

FORMAL TRAINING IN THE BIOLOGIC SCIENCES

But to consider the formal training first, it is to be noted that the college offerings in the biologic sciences are not always adapted to the needs of prospective teachers. Many of the college and university departments in botany and zoology still specialize on professional courses for future research investigators. The fact that about 80 per cent of their majors, A.M.'s, and Ph.D.'s subsequently earn their livings by teaching, and that nearly 100 per cent of the others who get into the departments (including pre-medical students) never make professional use of what they learn there, has had strangely little influence on the organization of those courses in the colleges. Of that fact most educators outside of the scientists themselves are well aware.

Courses intended for the prospective biology teacher might reasonably be most concerned with that portion of the living world with which he most often comes into direct contact. Courses in algæ, diatoms, minute fungi, mosses, protozoa, and marine invertebrates (when away from the seashore) are not important for one who has no intimate acquaintance with the world through which he is moving. Similarly, special courses in cytology, histology, embryology, and the comparative anatomy of vertebrates are concerned with structures and phenomena with which the high school teacher will rarely again have contact.

Specifically, the following college courses may be recommended for high school teachers in training. For the training of future college teachers and research workers many specialized courses must be added to those listed below.

Biology: a unified, principles, and survey course which includes a considerable amount of fieldwork.

General Zoology: a more specific introduction to the morphology, physiology, and general biology of the animal groups.

General Botany: a more specific introduction to plant groups, emphasizing the structure and physiology of vascular plants.

Birds: a field and laboratory course in bird identification, ecology, and behavior. There is no group of animals that may contribute more to one's enjoyment of the world.

Insects: a field and laboratory course in the identification and biology of insects, emphasizing insect behavior as a possible source of life-long interests for the average man and woman.

Systematics of Vascular Plants: This will contribute a great amount of material for the use of the teacher of elementary classes—and for one's own enjoyment of the world. Courses in "trees" and "spring flora" are in this field, but a more comprehensive program in systematic botany is needed.

Genetics (including heredity, evolution, and eugenics): often presented in too specialized a form, and hence to be recommended only if the student has had most of the other courses listed above.

Field Course in Vertebrates: covering mammals, reptiles, amphibia, and fish (omitting the birds, which are considered in a special course).

Cross-Country Field Course: a summer course travelling by auto, offering students an opportunity to see diverse life zones over a wide expanse of country.

This list includes more than most undergraduates can take, but the program can be continued in the work usually undertaken for an A.M. degree.

TRAINING IN THE BIOLOGIC VIEWPOINT

For students planning to teach biology it is unfortunate that so many of the colleges and universities maintain separate if not antagonistic departments in botany and zoology. It should be possible for undergraduates, and even for many graduate students, to work for majors or advanced degrees in biology, dividing their work rather equally between the two departments.

Beginning teachers who, in their training, have had some contact with a unified biology course should find it easier to present a unified program in the high school. If they have had considerable work in both botany and zoology, they are more likely to draw on both plant and animal materials to illustrate biologic principles. Research students who have worked in both departments will come to see ramifications in their problems and significances in their materials that will not be apparent to the worker trained only in botany or in zoology. It is not enough to believe that capable teachers and research men make up many of their deficiencies after they have graduated from college. In actuality, very few of them ever acquire a biologic viewpoint if they have not had contact with it as undergraduate or graduate students.

A NATIVE INTEREST IN PLANTS AND ANIMALS

A native interest in plants and animals is the qualification most often lacking among high school and college teachers of the biologic sciences. There is no substitute for this out-door background for teachers of beginning classes, either in the high school or the college. It is the living world to which any beginning course should introduce its students. *The teacher with nothing but a laboratory veiwpoint can never lead students to see the connections between the book knowledge and the world through which they move.*

It is very much to the advantage of the teacher if his interest in the out-of-doors was developed while he was still young. There is much gained if such an interest develops before or at high school age. The boy or girl finds the learning of the names of trees, of birds, of bugs, and of flowers a game which may weary the inexperienced adult. The boy or girl can and will devote hours to tracing down the history of a weed, will watch an ant colony for days without end, will gather cocoons to breed moths, and similarly investigate seemingly commonplace things which the uninitiated adult does not find as important as the other affairs of the day.

Too many of the high school biology teachers have turned to biology only at the end of their college courses when they needed a "second" or a "third" teaching subject for their state licenses. Too many others, with original interests in commercial bookkeeping, in German, or in other equally unrelated subjects, have come into science only in recent years and because biology needed more teachers than some of the older subjects. These teachers rarely compare with those whose interests as boys or girls were in the out-of-doors.

The quality of our biology teachers, and even of our research biologists, will depend, therefore, to a great extent upon the boys and girls who are now developing their interests in this living world. The high school teacher really occupies a strategic position in the training of these future biologists.

INDEPENDENT, POST-GRADUATE DEVELOPMENT

It may well be debated whether the prolongations of the college program are as significant in the development of the biology teacher as an independent study of the actual materials of the science.

Making up for the lack of earlier experience, or extending one's previous studies, the teacher should set himself to *becoming acquainted with the common plants and animals* of the region in which he is teaching. He should learn their names, how to identify them, and something of their biologic peculiarities—where they are found, the soil, food, or shelters on which they depend, their life histories, economic importance, etc. Thus one may come to know where to turn, among common things, for illustrations of the biologic principles and phenomena being presented in the classroom. There is nothing that will do more to enrich one's teaching.

The plant and animal groups most often useful in elementary teaching are the trees, other flowering plants, ferns, larger fungi, insects (to be identified only to families), birds, and some other vertebrates (mammals, reptiles, amphibia, a few fish). The list will vary with the location of the school. Such a systematic

study should involve the collection or recording by description of all the species that can be found in the region; the identification of the material with the help of the available reference books; and the first-hand accumulation of data on the biology of these species. Unless the teacher has had considerable systematic experience, it will be well to begin with the study of a single group, adding other groups in successive years. Notebooks, or lists, or marginal notes in the reference books should build a precise record of the progress of the study. Ultimately the teacher may want to undertake such an intensive study of a single species or family of plants or animals as might contribute even to the research literature of biology.

The pursuit of these independent studies will be greatly facilitated if the school or the teacher builds a library of real reference books. The reference material used by high school teachers too often includes nothing but an accumulation of current high school texts. Texts are at the best second-hand, and often tenth-hand sources of information. For independent field studies one needs the help of such special literature as that listed at the end of Chapter XVII.

The teacher's systematic study of the local fauna and flora should extend beyond the classroom teaching. Now and then some of the more interested members of the class might well be included on some of the trips of exploration, and the whole class will always be interested to know that the teacher is engaged in such a study, and will want to share some of the new discoveries that he may make. But the teacher's studies will take more time and go far beyond what the class as a whole can undertake.

We may despair of ever seeing a live biology in the schools unless the teachers are interested enough in this living world to explore it whenever opportunity affords. This will demand the use of afternoon hours, time in the week ends, holidays, and summers. If school administrators are persuaded of the value of such work, they may relieve the biology teacher from the supervision of extra-curricular activities. In fact, school officials and the community might very well wonder about the qualifications of a biologist who is never known to turn to the woods and

the fields except when the scheduled routine requires it; but they may come to have considerable respect for the teacher who is continually browsing around out-of-doors, acquiring at first hand the materials on which his teaching is to be based.

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CHAPTER XXV

THE BIOLOGIC VIEWPOINT IN THE COLLEGE

THROUGHOUT THE PRESENT VOLUME, the justification of the unified, survey, and principles program in biology, its objectives, content, and techniques have been discussed in their relation to both high school and college courses. There is no need of repeating or summarizing this material as it applies to the higher institution. The present chapter is concerned with those problems which are peculiar to the college.

STUDENT INTERESTS INVOLVED

The college department of botany, zoology, or biology, would seem to have five functions:

1. To contribute to the liberal education of the mass of students.
2. To contribute to the professional training of students in such other fields as medicine, psychology, agriculture, home economics, etc.
3. To train biologists for such economic fields as entomology, forestry, phytopathology, ornithology, etc.
4. To train teachers in the biologic sciences, both for the high schools and the colleges.

5. To train research biologists for university positions (which are usually combined with teaching), and for positions in museums and research institutes.

Which of the five groups of students is most numerous in any particular instance may depend on local conditions, but in many cases merely reflects the department's concept of its own functions. There are colleges in which the biologic sciences touch nearly every student in the school, and there are departments which draw few outside of majors or professional students for whom the work is required. That this latter condition more often holds in zoology and less often in botany may be due to intrinsic differences in the materials of the two subjects, or to the fact that the zoologists can get a pre-professional clientele without working for it.

Some of us feel that the biologic sciences in the colleges have their greatest opportunity in contributing to the liberal education of the body of our students. As more and more of our youths demand a college education, and as an increasing number of them are engaged in professional programs, it becomes increasingly important to frame courses so these students may gain a balanced view—even if an elementary one—of biology as a whole. Though they may be majoring in totally unrelated fields, they are all concerned with their own lives, and with the living world through which they must move. The biologic sciences may occupy a unique place in the program of the liberal arts college.

As an introduction for such special biologic fields as economic entomology, forestry, etc., a broad course in general biology is similarly used with increasing frequency. With the significance of such a course for the pre-medical and pre-dental students there may be more debate; but the American Committee on pre-medical training is inclined to ask for just such a broad and unspecialized introduction to the sciences as the unified course would provide. General biology may give pre-medical students the biologic backgrounds of nutrition, metabolism in general,

disease, immunity, epidemics, behavior, heredity, insect relations to disease, and still other things. In biologic science there is more for the pre-medical student than the specific anatomy with which so many of the present pre-professional courses in zoology are concerned. In addition, it is to be pointed out that the physician may find the world of plants and animals quite as interesting a diversion from his specialized pursuits as the other professional men for whom we have argued the advantages of a survey course in biology.

Chapter XXIV is concerned with the training of high school biology teachers. In their teacher training some of the colleges have taken cognizance of the changes which have taken place in recent years in the high school program. In other instances there is a rigid adherence to the program of thirty years ago—the morphology type course which nearly killed the biologic sciences in the secondary schools.

For the training of the future college teachers, the colleges have depended on the Ph.D. program, emphasizing the completion of a piece of original research. The breadth of the training in fields outside of the subject of research has usually not been great. The increasing divergence of the subjects of research, and recent suggestions that the training of college teachers should be taken over by the schools of education, are beginning to make some of the university men question whether the training for college teachers is as effective as it was in an older day when biology was a smaller field, and when research problems were not so remote from the elements of the subject.

College instructors engaged in very special fields of research· naturally look to the graduate students who come under their direction for the perpetuation and advance of their own or related fields of study. In all frankness, it is to be admitted that there is little recognition of the fact that the student will, in all probability, have to make good as a teacher before he will find the opportunity to pursue research.

The defense to be given for the teacher training program based on research, is its value in showing the differences between

direct observation and second-hand authority as sources of information. This is a thoroughly sound argument. But one may still question the value of a thesis-centered program for the training even of college teachers.

That a year or more of the Ph.D. program should be given to formal training in pedagogy or to research in methods of teaching is a suggestion to which most science teachers do not subscribe; but there seems very good reason for recommending one good course in pedagogy, some consideration of special methods in the subject involved, and supervised teaching experience as educational requirements for college teachers. In most universities graduate assistants are employed to conduct laboratory and conference sections, and there is an ideal set-up for a supervised teaching program. Whatever the pretense, however, such assistants are rarely supervised with anything like the care that critic teachers use in the secondary schools. But here the academic departments could, if they would, contribute invaluable guidance to graduate assistants.

What the Ph.D. may most need is modification in the direction of breadth. The undergraduate and graduate courses, between them, should round out a fair introduction to the biologic sciences as a whole: botany, zoology, and bacteriology. This would include entomology, human physiology, and such other sub-divisions of biology as are sometimes segregated in separate departments. The broad field in which the thesis lies might become the subject of a series of critical papers or outlines such as the good college teacher might prepare before undertaking to present similar material to a class of undergraduates. The preparation of this material might well occupy as much time as the original research thesis. Such a program would improve the training of college teachers by encouraging a sort of scholarship which is quite different from ability as an original investigator. The graduate schools have been producing some research students, but a much smaller number of scholars. More attention given to the development of scholarly attitudes might contribute materially to the quality of college teaching.

COORDINATION OF HIGH SCHOOL AND COLLEGE COURSES

There is some apprehension among educators that the introductory courses in the college sciences are mere repetitions of the high school courses in the same subjects. It is pointed out that college courses in mathematics and the languages build on top of the high school work, and the failure to make a coordination in the sciences makes it appear that time is being wasted in the colleges, or else that the teaching is not effective in the high schools. The problem thus raised may be, however, more apparent than real. It is true that examinations given incoming freshmen in college do not indicate that many of them are able to enter advanced science classes; and the sectioning of college classes on the basis of their previous experience does not indicate that college performance is very much affected by high school contacts with science. But this is neither evidence of the futility of secondary teaching, nor warrant for repetition of high school courses in the colleges.

Probably the most important factor, and one frequently overlooked in these discussions, is the difference in age of the high school and the college students in biology. The high school course is offered in the ninth or tenth year. The college course in biology may enroll students anywhere from their freshmen to their senior years. The college course comes from three to seven years after the high school course. The years intervening include the most significant period of adolescence. They mean a great deal in the development of the thinking ability of the student. At thirteen or fourteen he gets certain things out of the high school course which make it worth-while for him; at seventeen or eighteen (or later) he can see more significance in the very same things.

These considerations may not be as significant in chemistry or in physics, for those sciences are offered in the last two years of the high school, and followed within a single year or two by the college courses in the same subjects. In those cases, it

may be more reasonable to expect that the college presentation be built more directly on that of the secondary schools.

The college course in biology, however, may be close to the high school course in content but very different in general level —in the quantity and quality of the work expected of the student. The high school course is always planned for a year; that in the college may cover as much material in a single semester, though a full year's course is offered in many institutions. The college course may include detailed materials, and such topics as human heredity, human evolution, biologic bases of society, etc., which are less appropriate for thirteen-year-olds.

DEPARTMENTAL ORGANIZATION

The effective development of a biologic program for undergraduates and the development of biologic attitudes among graduate students will inevitably call for some change in the traditional organization of departments of botany and zoology.

Putting traditions and political considerations aside, a few of the largest and most forward institutions have effected some coordination of their biologic sciences, and others are more gradually evolving in that direction. The organization outlined below does not represent the plan found in any particular institution, but it may be offered as a composite of such organizations as have already been or are slowly being developed.

1. A Biological Division which includes all the biologic sciences (botany, zoology, entomology, bacteriology, etc.), with the exception of the advanced work in the professional schools (*e.g.* medicine, agriculture, etc.). All undergraduate majors and graduate degrees are taken in this Division rather than in special parts of it. The theses for research degrees deal with parts of this whole Division, just as cytology, embryology, or endocrinology, for instance, now constitute special research fields in zoology. The entire faculty of this Division, with a Chairman, is in charge of all undergraduate majors and of all advanced degrees. It is in charge of all courses which are not exclusively

botany or zoology, and of all necessary coordinations, prerequisites for, and sequences of, courses in the Division.

2. A unified biology course pre-requisite to all other work in the Division. The course is under the control of the Faculty of the Division, though it is given in some cases by one man, and in other cases by several contributors from the faculty.

3. Courses that are exclusively botanic are under a Head of Botany and a staff which includes all teachers of those courses. Here are the usual courses in General Botany, Plant Anatomy, Plant Physiology, Systematic Botany, Plant Pathology, etc. In larger institutions, several of these fields may constitute distinct faculties in the Division.

4. Courses that are exclusively zoologic are under a Head of Zoology and the staff teaching those courses. Here come the courses in General Zoology, Comparative Anatomy, Vertebrate Histology, Embryology, Vertebrate Physiology, Ornithology, Entomology, etc.

5. All advanced courses involving biologic principles are in charge of the Division Chairman and Faculty, and organized to present both the plant and the animal data available in the field. Here come the courses in Heredity, Evolution, General Physiology, Principles of Cytology, Principles of Taxonomy, Ecology, Limnology, etc. The courses in this group may contribute materially to the development of biologic viewpoints among the students.

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To believe that such an organization of the biologic program will be general among American universities within any short period of years would be to ignore the slow march with which evolution proceeds in academic circles. That some such organization will ultimately replace the present departments of botany and zoology is presaged by a growing conviction among college men that effective teaching and advances in research are soundly established only when the foundations are broadly biologic.

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* Recommended as the best references for student use.

APPENDICES

APPENDICES

BIOLOGICAL SUPPLY HOUSES

This list makes no pretence at being complete. There are other firms that have excellent service. The list as it stands will provide first aid for the less experienced teacher.

BAUSCH AND LOMB OPTICAL CO. Rochester, N. Y. *Lenses, microscopes, lanterns, micro-projectors, etc.*

BROWNELL, L. W. 176 E. 32 St., Paterson, N. J. *Lantern slides.*

CAMBRIDGE BOTANICAL SUPPLY CO. Waverly, Mass. *Collecting equipment, microscope and lantern slides, etc.*

CAROLINA BIOLOGICAL SUPPLY CO. Elon College, N. C.

CARTER, GEORGE S. Clinton, Conn. *Corn to show the 3-to-1 ratio.*

CENTRAL SCIENTIFIC CO. Chicago, Ill. *Skeletons, apparatus, etc.*

CHICAGO APPARATUS CO. 1735 N. Ashland Ave., Chicago, Ill.

CLAY-ADAMS CO. 117 E. 24 St., New York City.

CONRAD SLIDE AND PROJECTION CO. Glen Ellyn, Ill. *Lantern slides.*

DENOYER-GEPPERT CO. 5235 Ravenswood Ave., Chicago, Ill. *Charts, models, etc.*

FISHER SCIENTIFIC CO. 709 Forbes St., Pittsburgh, Pa. *Apparatus.*

GENERAL BIOLOGICAL SUPPLY HOUSE. Chicago, Ill. *Trade mark:* Turtox. *Dissecting equipment, laboratory apparatus, live and preserved material, microscope preparations, lantern slides, etc.* Turtox Service Leaflets: *many suggestions for laboratory and field work, obtainable gratis.*

GITS CO. 5419 W. Chicago Ave., Chicago, Ill. *A convenient knife for laboratory use, for making sections, etc.*

HAUSER, J. F. Bayfield, Wis. *Perennial plants in wholesale quantities for school plantings.*

HILL NURSERY CO. Dundee, Ill. *Evergreens for planting school grounds.*

INTERNATIONAL EDUCATIONAL PICTURES. 40 Mt. Vernon St., Boston, Mass. *Silent and sound films at reasonable rental fees.*

JEWELL MODELS. Carlinville, Ill. *Fine list of morphologic models.*

KEYSTONE VIEW CO. Meadville, Pa. *Lantern slides.*

LEITZ, E. 60 E. 10 St., New York City. *Lenses, microscopes, lanterns, etc.*

MARINE BIOLOGICAL LABORATORY. Woods Hole, Mass. *Live and preserved marine material.*

NATIONAL AUDUBON SOCIETY. New York City. *Lantern slides, pamphlets on birds, bird pictures, etc.*

NEW YORK BIOLOGICAL SUPPLY HOUSE. 34 Union Square, New York.

NYSTROM, A. J. 3333 Elston Ave., Chicago, Ill. *Charts and maps.*

RAND-MCNALLY & CO. New York City, Chicago, San Francisco. *Atlases, pocket maps, outline maps, etc.*

SOUTHERN BIOLOGICAL SUPPLY CO. 517 Decatur St., New Orleans, La.

SOUTHWESTERN BIOLOGICAL SUPPLY HOUSE. 211 S. Polk St., Dallas, Tex.

SPENCER LENS CO. Buffalo, N. Y. *Dissecting instruments, lenses, microscopes, lanterns, micro-projectors, etc.*

STANDARD SCIENTIFIC SUPPLY CORP. 34 W. 4 St., New York City. *Charts, models, dissecting material, apparatus, etc.*

STORRS AND HARRISON NURSERIES. Paynesville, Ohio. *Trees, shrubs, perennials, etc., for planting school grounds.*

SUPERINTENDENT OF DOCUMENTS. Washington, D. C. *Maps and many biologic publications. See especially price lists* 11 (Foods and Cooking), 16 (Farmers Bulletins), 21 (Fishes), 35 (Geography and Explorations), 38 (Animal Industry), 39 (Birds and Wild Animals), 41 (Insects), 43 (Forestry), 44 (Plants), 51 (Health), 53 (Maps).

WARD, C. H. Rochester, N. Y. *Models, skeletons.*

WARD'S NATURAL SCIENCE ESTABLISHMENT. Rochester, N. Y. *Models, preparations, apparatus. Only makers of Schmitt boxes and American Entomological Society pins; other insect collecting equipment.*

WELCH SCIENTIFIC CO. 1516 Orleans St., Chicago, Ill.

WILL CORPORATION. Rochester, N. Y. *Dissecting instruments, laboratory supplies, etc.*

ZEISS, CARL. Agency. 153 W. 23 St., New York City. *Lenses, microscopes, etc.*

SELECT REFERENCE LIST: METHODS IN TEACHING BIOLOGY

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TEXTS, SUPPLIES, PROBLEMS, AND TESTS

For lists of the following, see the indicated pages in the body of the text:

INDEX

INDEX

INDEX

INDEX